ORIGIN THROUGH EVOLUTION

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ORIGIN THROUGH EVOLUTION

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FIG. 1. A CALIFORNIA REDWOOD

The General Sherman Tree, the largest and oldest living tree in the world. It rises to a height of 280 feet above the ground, while its circumference at its largest point measures 103 feet. The automobile at the foot gives a comparative idea of its great size.

ORIGIN THROUGH EVOLUTION

BY

NATHAN FASTEN, PH.D.

PROFESSOR OF ZOÖLOGY IN OREGON STATE AGRICULTURAL COLLEGE

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To My Wife

FRIEDA MAYER FASTEN

Loyal Companion

Splendid Mother

Judicious Critic

PREFACE

This book has been written with two ends in view. First, the author has sought to produce a text which can be used by the average conscientious student who, although possessing little or no scientific background nor any desire to specialize in a technical field, nevertheless is eager to comprehend the forces and factors which have been responsible for the various material expressions of the evolutionary process. Second, he has held in mind the interests of the intelligent layman who wishes to obtain accurate information on one of the most widely-discussed topics of the day — evolution.

Many of the older and more recent books on evolution are so technical that only a scientifically trained individual can read them with full understanding. Intelligent laymen, as a rule, have left such volumes alone, and have sought to obtain their information on this important subject from pulpit orators or popular writers, many of whom were either unfamiliar with the facts of evolution or else disposed to misrepresent and distort them in such a way as to convey an utterly erroneous impression. Obviously, such a situation must inevitably do a great deal of harm, and may be held largely responsible for the attacks which have been launched by many communities against the teaching of evolution in various educational institutions, particularly those supported by public funds.

The present treatise, therefore, is an attempt to present the facts of evolution as the scientist sees them, in a manner which can be understood not alone by the trained student, but also by the fair-minded and truth-seeking layman. No previous knowledge of the subject is assumed on the part of the reader. All scientific terms and technical details have been defined or explained in simple, straightforward language easily comprehended by any person of normal mentality.

The writer wishes gratefully to acknowledge the kindness and courtesy of the various authors, editors, and publishers, who have granted him permission to use either excerpts or illustrations from their respective publications. In particular, he desires to express such appreciation to the Open Court Publishing Company of Chicago, and the Science Press of New York. The author also thanks his colleagues, Professors Earl Gilbert, Bess Rose Green, Edward Maris Harvey, and Douglas C. Livingston for reading critically various portions of the manuscript and making numerous helpful criticisms and suggestions. To his wife, Frieda Mayer Fasten, he owes a debt of gratitude for her many critical readings of the entire manuscript and her painstaking work in drawing most of the original illustrations. Without her constant encouragement and unfailing devotion the volume could never have become an actuality.

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ORIGIN THROUGH EVOLUTION

CHAPTER I

MATTER AND ITS ORIGIN

SCIENCE deals with matter and its various manifestations in nature. While there are some philosophies which do not regard matter as an actuality, it is none the less true that the very foundations of science rest upon the reality of the existence of matter. The aims of science are, in the main, to discover those laws which underlie and control the various material expressions. To the scientist, matter is real; it exists. Furthermore, it has two attributes which disclose it to our senses: it possesses some mass or, as we commonly term it, weight; and it also occupies a certain amount of space, as measured by the three dimensions of length, breadth, and thickness. Everything around us adheres to these two criteria. It is safe to say, therefore, that matter is not only the foundation of the sciences, but the foundation of all that reveals itself throughout space.

From time immemorial man has wondered how material things originated. Before the advent of modern science, the great question which human beings tried to solve was how the first matter came into existence; and, failing to find any adequate answer, they soon regarded it as mysterious and beyond solution. Incidentally, it led great minds into absurd scholastic disputes which brought about an absolute stagnation of

scientific thought. Modern man is not greatly concerned with the origin of matter; rather, he is interested in trying to solve what he sees before him, to analyze and explain the present-day manifestations. When we study the history of thought we find that there have been some four answers to the problem.

One explanation is called "the eternity conception," according to which matter is regarded as everlasting; it has no beginning and no end; it never changes. This explanation does not satisfy any of us, for it does not answer the question at all. We like to think of phenomena from the standpoint of cause and effect, but here cause and effect are lost in the abyss of Infinity. Today there are very few laymen and almost no scientists who hold this point of view.

The second explanation is one which has held sway for countless ages; many people still accept it. It is commonly termed "the Mosaic doctrine of special creation," and is pleasing particularly to persons who have had no scientific training. It is the idea which one derives from a literal interpretation of the first chapter of Genesis in the Old Testament. This presents a wonderful picture of how our universe originated. According to the description, everything which exists at the present time was created in the short period of six days; all was completed in this very insignificant space of time, and since then there has been no modification.

Persons who accept this view also believe, with the one-time venerable Archbishop Usher of England, that creation was accomplished and completed some four thousand years before the Christian era. Andrew D.

White tells us that the most precise date is that fixed in the seventeenth century by the great rabbinical scholar, Dr. John Lightfoot, Vice-Chancellor of the University of Cambridge, who asserted that "heaven and earth, center and circumference, were created together in the same instant, and clouds full of water, . . . and man was created by the Trinity on the twenty-third of October, 4004 B.C., at nine o'clock in the morning." [1]

One wonders how many of us, writing at the time when the first chapter of Genesis was conceived, before the birth of science, could have developed a picture more beautiful than that there presented. It is truly a marvelous story, one that kindles the imagination; but within the last few hundred years scientists have made numerous discoveries which contradict it, and it has therefore been rejected on the ground that it is not literally correct.

To substantiate the statement that Genesis is incorrect, it is necessary to cite only one illustration of its inconsistency with modern scientific discoveries, namely, the great age of some of the giant redwood trees (Figure 1) in California. Many botanists have called attention to the fact that some of these trees, judged by their size and by the diameters which they attain and, more particularly, by the number of growth rings which they reveal, are probably more than four thousand years old. Furthermore, it is quite certain that redwoods existed for many thousands of

[1] White, Andrew D., *History of the Warfare of Science with Theology in Christendom,* New York, Appleton, 1896, vol. I, p. 256.

years before those of California even came into being. At Florissant, Colorado, geologists have found vast areas covered by petrified stumps which at one time were living redwoods. Many of these show definitely that they attained an age of several thousand years before they died; and assuredly it must have taken a great many times the age of the trees themselves for petrifaction to set in.

Here, however, a word of caution is essential to clarify the point of view. What is the big concept which is found in the first chapter of Genesis? If read correctly, it reveals that the individuals who wrote it endeavored to express the idea of Creation through the act of a Creator. Science finds no fault with such a view, and if the chapter be interpreted in this light, as it is interpreted by a great many liberal-minded theologians and scientists, then it has a significant meaning; but if one attempt to accept it verbally, it becomes of no value. One must remember that Genesis was written several thousand years ago, at a time when the scientific knowledge which we possess today did not exist. An intelligent modern youth knows more of science than did any of the ancients! The world has not stood still during the last few thousand years; the many advances in the fields of biology, geology, astronomy, chemistry, and physics have come in recent centuries. The idea of Creation through the medium of a Creator, the idea that there is something back of the universe, is the big concept which the first chapter of Genesis has for its theme; and when thus interpreted, the scientist has absolutely no objection to it. He finds

Fig. 2. Georges Cuvier

fault with those who accept it only when they insist on the literal plan of Creation as there described.

The third conception, that of cataclysms or catastrophies, was developed by the French genius Cuvier (Figure 2) at the beginning of the nineteenth century, and it surpassed even the Mosaic idea of special creation. Cuvier, who lived from 1769 to 1832, was not only

the greatest French scientist of his time, but also a devoutly religious man. He believed that the Bible was infallible, and that nothing in it was to be questioned. Considering it not only a book of revelation, but also a book of true science, he felt that everything which he accomplished had to harmonize and strengthen it. Cuvier, besides being an eminent comparative anatomist, was also a distinguished paleontologist, one who studies the past records of life upon the earth as revealed by the fossil remains found in the earth's formation. He soon discovered that there had existed on this earth a great many plants and a great many animals which had disappeared before his own age; speculating about these anomalies, he concluded that there must have been change. This, of course, was directly contrary to the belief in special creation, and Cuvier was so disturbed that he endeavored to harmonize his findings with the current opinion. Therefore he promulgated a theory to the effect that numerous cataclysms or catastrophies of indescribable violence had visited the earth at different periods, and that each cataclysm had been succeeded by a new act of creation; only in this way, he believed, could one account for the many new plants, animals, and earth formations which had successively existed in bygone times.

In order to make this theory clear, let us assume that a certain portion of our earth, after the first act of creation, was visited by a great cataclysm which completely destroyed the land formations and the life which existed in the particular locality. How did this devastated area take on new form and life? According to

Cuvier's assumptions, it was accomplished either by another act of special creation or by a migration of living things from the surrounding regions which soon re-populated and transformed the afflicted place. Cuvier did not specify the exact number of such catastrophies and re-creations, but some of his contemporaries estimated their number at anywhere from two or three to as many as twenty-seven. The Mosaic accounts of creation and the flood, as set forth in the Old Testament, were looked upon as descriptions of the last acts of creation, destruction, and re-population which took place on our planet.

Even though Cuvier assumed change and a succession of life, he was not an evolutionist; indeed, he was definitely opposed to the idea and fought it vigorously. He sneered at the evolutionary conclusions of Lamarck (Figure 3), one of his contemporaries, and stubbornly resisted the promulgation of similar views. He also engaged in a series of famous debates on evolution with another French scientist by the name of St. Hilaire; but Cuvier, being a skilful logician, completely overwhelmed his opponent with his oratory and hopelessly defeated him. The day was won for the "Formalists," or, as we now call them, the "Fundamentalists." In spite of his antagonism to evolution, however, Cuvier nevertheless assumed change and thereby contributed to evolutionary thought; for change is the very essence of evolution! No scientist today accepts the cataclysmic or catastrophic theory of the origin of matter.

The last explanation of the universe and the matter contained therein is embodied in the theory of evolution.

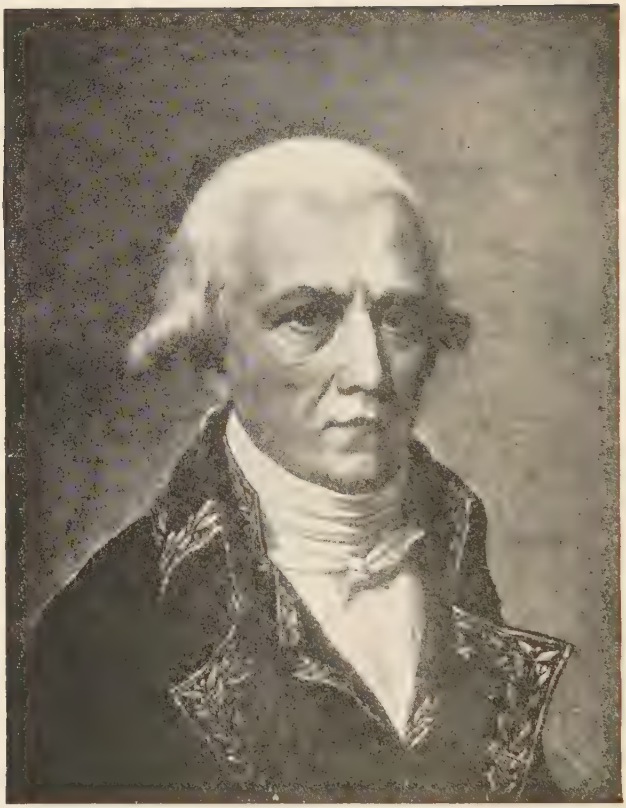


Fig. 3. Jean Baptiste Lamarck

This is the modern conception, and intelligent people are united in accepting it. The scientist, on his part, believes that evolution is God's way of creating matter in its present forms, through a slow, logical, definite, and orderly process. The American poet, Carruth, has beautifully expressed this idea in his well-known verse:

A fire mist and a planet,
A crystal and a cell, —
A jelly-fish and a saurian,
And caves where the cavemen dwell —
Then a sense of law and beauty,
And a face turned from the clod;
Some call it *Evolution,*
And others call it *God.*[2]

Evolution may be defined as the subject dealing with those facts and principles which account for present as well as past expressions of matter, animate and inanimate, throughout space. It is a grand conception which unifies all phases of nature and makes everything conform to the same underlying orderly forces and principles that control the various expressions in nature. It is a doctrine that shows us how present matter, in all of its forms, has gradually come into existence from simpler beginnings. As the idea has been so often expressed, " the present is the child of the past, and also the parent of the future." This statement embodies the evolutionary idea, and it is full of promise for the ages to come. Change is the very essence of evolution, and through it have arisen, by gradual processes, all of the material things which now exist; through it, also, the present order will become modified into a more nearly perfect state.

What a dynamic point of view, and how different from the static idea of special creation! The latter reduces everything to a cut-and-dried process of fixity,

[2] Carruth, William Herbert, *Each in His Own Tongue and Other Poems,* New York, G. P. Putnam's Sons, 1911.

whereas evolution shows us a continuous panorama, with the scenes ever changing and new creations constantly arising, conditioned and linked by an infinite number of indissoluble ties to the old order of things. Special creation is revolutionary, while evolution is orderly, slow, and progressive! Professor Edwin Grant Conklin states:

> As between evolution and special creation we have to choose between two theories or hypotheses, and it is merely a question of evidence as to which is the more probable. All the evidence available supports the theory of evolution; it continually receives fresh support from new discoveries; it is not contradicted by any scientific evidence. Can the supporters of the theory of special creation say as much? [3]

The evolutionist believes that the same specific forces which account for the first expressions of matter are still operative in the universe, and will continue to produce new things so long as matter continues to exist. Furthermore, these things will become more complex and more nearly perfect as the ages roll by. Evolution holds good for all nature, both animate and inanimate; except in a superficial way, it makes no distinction between these two expressions. First, inorganic matter appeared, and this slowly evolved to ever higher levels of complexity. As soon as conditions were right, organic materials made their appearance; and following them, in due course of time, came living substances. The entire story is one of endless progress from very lowly

[3] *The Direction of Human Evolution,* New York, Scribner, 1922, p. ix.

beginnings. Evolution may be likened to a continuous motion picture, the scenes of which are changing so imperceptibly that each diffuses into the other, and this takes place by such a gradual process that one perceives only the grand spectacle, forgetting that it was made possible through a great number of slight but nevertheless distinct modifications of view.

The plan and purpose of the following chapters is to disclose the basis for the scientists' faith and belief in the evolutionary doctrine.

CHAPTER II

MISCONCEPTIONS

In the last few years numerous attacks have been launched against the teaching of evolution in the various schools and colleges of this country. This has been due largely to the efforts of the so-called "Fundamentalists," who have been spurred to action by such zealous champions of the Bible as the late William Jennings Bryan. Those who read the current magazines and newspapers have undoubtedly followed the controversies which have been going on. Almost daily somebody is quoted as stating this against evolution and that for it, with the result that the average layman does not know what to believe. Furthermore, numerous misconceptions have been circulated to such an extent that real harm has been done. It is time, therefore, for the evolutionist to speak, not only to defend his doctrine, but to inform the public as to what is correct and what is incorrect in evolution.

In this age of specialization, who shall be considered an authority in a certain field if not the so-called expert? For medical advice and treatment we call in the doctor; for legal guidance we consult the lawyer; in mechanics we regard the engineer as the authority; but in regard to evolution, many honest people forget that this also is a sphere in which only persons qualified to speak

should make assertions. Unfortunately, many of those who are attacking evolution either are totally ignorant of the facts or have a meager, undigested knowledge of the subject. Conklin comments on this as follows:

In general, the opponents of evolution have neither the technical ability nor even the desire to weigh critically the evidences for the truth of evolution. Properly to appreciate these evidences requires some first-hand knowledge of morphology, physiology, embryology, ecology, paleontology, and genetics. In science, it is necessary to see and handle actual material and processes in order to appreciate their significance, as all who have worked in laboratories know. The advice which Huxley gave to the " paper philosophers " of his day is still good advice: "Get a little first-hand knowledge of biology." But the opponents of evolution not only lack such first-hand knowledge; they usually have no desire to get it second-hand from those who have studied nature. One of these denouncers of Darwin, when asked if he had ever read his books, replied: " I wouldn't touch them with a ten-foot pole." Neither facts, evidences, nor sweet reasonableness can penetrate such an armor.[1]

Dr. Edward L. Rice,[2] in an address entitled " Darwin and Bryan, a Study in Method," delivered a few years ago before the zoölogy section of the American Association for the Advancement of Science, indicated the real difference between the approach of the scientist and that of the individual trained in other fields. Dr. Rice showed how exhaustive was the work of Darwin; how

[1] *The Direction of Human Evolution,* New York, Scribner, 1922, p. vii.

[2] *Science,* vol. 61 (1925), pp. 243–250.

he, Darwin, reached his conclusions only after extensive travel and the examination of innumerable facts accumulated over a period of more than twenty-five years. Dr. Rice also indicated the method of the late Mr. Bryan, who through derision, through the gift of mere oratory and the disregard of facts, attempted to destroy the evolutionary doctrine. Unfortunately, there are many persons who believe that by condemning another view they strengthen their own position. In the last analysis, however, it must be recognized that all sincere persons are interested in ascertaining the truth, no matter into what channels it may lead. The scientific man as well as the religious man must kneel before this altar of truth. In order to be convinced of the fact of evolution, one must approach the subject with an open mind and study its evidences patiently. Derision and mockery are the weapons of the charlatan and the fanatic.

Scientists are slowly awakening to the fact that they must emerge from the seclusion of their laboratories long enough to grapple with this situation. David Starr Jordan,[3] commenting a short time ago on a little volume by Dr. William M. Goldsmith entitled *Evolution or Christianity*, expresses regret that in this day and age a book of this sort should have to be written to dispel the notion that because a man is an evolutionist he cannot have any religion. A few years ago the author met a number of English educators in British Columbia who expressed great surprise that a controversy of this nature should be taking place in democratic America in

[3] *Idem*, p. 45.

the twentieth century. They could hardly conceive of such an occurrence in Great Britain, stating that they had passed through a similar period about sixty years ago, and that since then they had accepted evolution as one of the noblest doctrines ever developed by the human mind. They are firmly convinced of the validity of the conception. Yet with us it is now an open question, with honest believers on both sides, many of whom are so disturbed that they forget some of the great principles which underlie real religion: namely, justice, truth, and tolerance.

One of the most common objections to evolution is that it leads to materialism, and that all believers in the doctrine are crass materialists. The answer depends on what one means by " materialism." As stated in the preceding chapter, the basis of all science is matter. The evolutionist deals with material things, with all of the manifestations of nature, and he tries to discover the laws which underlie their operation. He attempts to explain all phenomena in a rational manner. He does not believe in supernatural causes, and avoids the assumption of mysterious explanations. He moves in whichever direction his facts lead him, and when he reaches a barrier he works patiently to surmount it. If he fails, he does not therefore postulate a mythical explanation; he simply halts and honestly states that he has been able to go thus far and no farther. He wishes to solve what he sees before him and tries to link up cause and effect. He does not read anything into his analyses; he gives exactly what he finds and no more. This is what is commonly called the inductive laboratory method,

and all scientists, when judged by such a standard, are materialists.

On the other hand, if one uses "materialism" as synonymous with "mechanism" — signifying that everything in nature is simply an expression of the blind interplay of chemical and physical forces — then most scientists are not materialists. They are, rather, mechanical-vitalists, believing that in the operations of matter there is something more than merely a machine-like interplay of particles and forces. In reality, it might be said that every evolutionist is a materialist from a laboratory standpoint; but once he divorces himself from these surroundings, he then becomes an idealist, dreaming of nobler things, of a better and happier world. He then sees design and purpose behind all nature.

Thomas Henry Huxley once said:

> There can be little doubt that the further science advances, the more extensively and consistently will all the phenomena be represented by materialistic formulæ and symbols. . . . But the man of science who, forgetting the limits of philosophical inquiry, slides from these formulæ and symbols into what is commonly understood by materialism, seems to me to place himself on the level with the mathematician who should mistake the x's and y's with which he works his problems for real entities, and with this further disadvantage as compared with the mathematician, that the blunders of the latter are of no practical consequence, while the error of systematic materialism may paralyze the energies and destroy the beauty of life.[4]

[4] "On the Physical Basis of Life," 1868.

A second misconception is that evolution does away with the Bible and, particularly, denies the validity of the Mosaic plan of creation. The fact is, however, that no sane person, let alone any scientist, would want to do away with so wonderful a book as the Bible. The scientist objects only to its acceptance as a modern treatise on scientific subjects. He regards the Bible as a human document conceived during the infancy of civilization, when there was either no science at all, or very little of it. He believes with a great many intelligent laymen and theologians that the Bible records the spiritual development of the human race at an early stage in the progress of civilization. Many students of religion have discovered that even the Bible reveals a distinct evolution, pointing out that there are marked differences between the earlier and later portions of it. This is exactly what one should expect to find in any human document covering a long period of time, for it probably took more than a thousand years for the various parts of the Old Testament alone to be written. The New Testament dates from a considerably later period.

Did the writers of the Bible know modern science? Those who insist that they did are utterly ignorant of history. It is only within the last few centuries that men have been allowed to think with any large degree of freedom, and the previous progress in science was extremely slow. In the last hundred years there has been more scientific accomplishment than in all of the preceding centuries. No sane person nowadays would think of going back to the superstitions and dogmas of the

Dark Ages, for they have been completely dispelled by our newer knowledge! Why, then, should the Bible be a lone exception? Reverend Lyman Abbott, a short time before his death, aptly described the situation when he wrote:

> If we use the Bible as a scientific authority, we misuse the Bible. We use it aright when we use its stories of spiritual disaster and spiritual achievement as warning, instruction and inspiration for our lives.[5]

Concerning the validity of the Mosaic doctrine of special creation, little more need be said. This explanation was undoubtedly the one prevalent at the time when the first part of Genesis was written; and as the best available account it satisfied people who possessed no scientific knowledge. But the progress of the last few thousand years has brought to light an infinite number of scientific facts which have disclosed a method of creation quite different from that depicted in the Bible. This, as already mentioned, is the evolutionary doctrine, which teaches that everything which exists has come from simpler, pre-existing structures through a slow, orderly process of change. Non-living as well as living creations have been formed in this way. The scientist believes that all of the available facts support the evolutionary conception, and that therefore it should be accepted by all serious-minded persons. August Weismann remarks:

[5] "Use and Misuse of the Bible," *The Outlook,* vol. 130, (1922), p. 290.

It is only a weak religion which is incapable of adapting itself to the truth, retaining what is essential and letting go what is unessential and subject to change with the development of the human mind.[6]

A third criticism often heard is that evolution teaches atheism by denying the existence of God. This is absolutely unjust and fallacious. While evolution neither affirms nor denies the existence of God, there is nothing which gives one a finer insight into the intricate laws and ramifications of nature than does evolution. When one contemplates the complexity, and withal the harmony, which exists among all objects in space, one cannot but form an idea of design behind nature. Does this smack of atheism? Every scientist is inspired by the grand spectacle of nature which reveals itself to him. He is filled with awe and wonder at the marvels of the universe. To the scientist, God is that wonderful harmony which pervades and unifies all nature; it is that something which is behind everything that exists. In a word, all nature is a manifestation of God and the Divine Will! It is what Tennyson meant when he wrote: "Yet I doubt not through the ages one increasing purpose runs."[7]

Many erroneous notions have been broadcast regarding evolutionists, and they would be amusing if many people did not take them seriously. Often ministers have made statements to the effect that from fifty to ninety per cent of scientists are atheists. Since there are no adequate data bearing on the subject, it is

[6] *The Evolution Theory,* London, Arnold, 1904, vol. 1, p. 8.

[7] "Locksley Hall," 1877.

difficult either to affirm or to refute these assertions. A few years ago Dr. Millikan, the distinguished physicist, in a commencement address delivered at Stanford University, quoted the results of an investigation conducted by Bishop Johnson of Los Angeles, to overthrow the idea that scientists were atheists. Bishop Johnson drew up a pious statement on the relation between science and religion, in which God was definitely recognized. Attention was also called to the fact that religion and science, instead of being in conflict, were rather to be regarded as handmaids necessary to human progress. The statement was sent to many prominent scientists, distinguished leaders in civic life, and outstanding clergymen. The results surpassed all expectations. Ninety-five per cent of the scientists signed the statement without hesitation, while only seventy-five per cent of all men of affairs and only sixty-seven per cent of all ministers affixed their signatures. Dr. Millikan then commented:

> The response of the scientists is particularly significant and possibly has some bearing upon the breadth of view developed by scientific training. After this showing, who is he who is asserting that science is materialistic and irreligious? There are a few scientists, it is true, who forget the scientific method when they touch the field of religion, and scoff at it without knowing anything about it, and these men, too, have their exact counterparts, perhaps in slightly larger numbers, in the field of religion, where there is, I regret to say, a group of blind leaders of the blind, men who still follow the method of the jungle and are still imbued with its spirit of prejudice, preconception and intolerance. Yet there is here the best of evidence that the leadership in both

science and religion is in the main imbued with both the spirit of intellectual honesty and objectiveness which is characteristic of science, and the spirit of altruism and service which is the glory of religion. This combination is the only nostrum which there is for human ills; the only hope for a paradise on earth, and each of us has the opportunity to do his bit toward bringing it about.[8]

A fourth misconception is that evolution destroys the religious concept of immortality. As already pointed out, science is opposed to dogma and superstition. Numerous dogmas and superstitions have developed in connection with immortality, and these have often been incorporated into religion as an essential part of the creed. Let it be emphasized that all of them have been man-made, and have changed with the progress of human intelligence. Immortality, literally translated, means life after death. Many individuals, therefore, have built up the idea of personal immortality through bodily resurrection at some future time, in some far-off place called "Heaven," where all earthly strife shall have ceased and peaceful contentment will reign forever. Science has no proof that such is the case, and scientists do not believe in this kind of immortality.

Evolution and science have developed a different notion of immortality, one which is concrete and applies to our social order from the standpoint of the immediate present and future. It is what is commonly called "biological immortality," which means so to live, so to reproduce, and so to influence humanity that the race of the future will be better equipped, physically,

8 "Science and Society," *Science*, vol. 58, (1923), pp. 293–298.

mentally, morally, and spiritually, than the race of the present. It desires to establish a better social order on earth for the purpose of making the civilization of tomorrow even finer than that of today. From this standpoint the aims of real religion and of evolution are similar. Religion has always looked forward to a "golden age," to a future period of peace, tolerance, and justice — in a word, to a brotherhood of man. Evolutionists believe that this can be brought about only by the development of a better race of men and women through the biological agency of reproduction.

A fifth criticism often hurled against the evolutionist is that he aims to undermine and destroy all religion. No greater fallacy has ever been perpetrated. We must remember that, after all, the fields of evolution and of religion are in many ways distinct. Evolution, belonging to the realm of science, deals with phenomena of nature; it attempts to describe them and to formulate laws which underlie them. Religion, on the other hand, deals with faith in something back of the natural plan of reality which is disclosed to our senses. William James expresses it well when he writes:

> A man's religious faith (whatever more special items of doctrine it may involve) means for me essentially his faith in the existence of an unseen order of some kind in which the riddles of the natural order may be found explained.[9]

It thus appears that evolution and religion are two distinct spheres, the one dealing with the realm of fact,

[9] "Is Life Worth Living," *The Will to Believe and other Essays in Popular Philosophy,* London, Longmans, Green, 1896, p. 51.

the other with the realm of faith. Still, there is no reason why the disclosures of evolution should not be incorporated into religion. The scientist desires a reasonable faith, and is convinced that the facts of evolution not only are compatible with real religion, but materially strengthen it.

For centuries the world has been struggling against superstition and dogma. The study of religions as a whole reveals a definite evolution from primitive to more rational views. Science has played its part in dispelling some of the fanatical beliefs held in previous ages. Shall it now be cast aside by religion? The scientist finds no fault with anyone who prefers to believe in a special set of articles of faith, but he insists that they are not essential to real religion, and he is convinced that a person can be virtuous, honest, truthful, and deeply spiritual without them. In fact, experience shows that the more an individual studies the arts, the sciences, and particularly evolution, the less dogmatic and superstitious he becomes, and likewise the more he comes to realize that the same essential moral teachings inhere in all of the great religions of the world. Moses, Jesus, Mohammed, Confucius, Buddha, and the other great religious leaders all taught surprisingly similar spiritual messages.

The evolutionist accepts truth and enlightenment from any source, regardless of race, creed, or color. Truth is truth, whether it be enunciated by Jew, Christian, or Mohammedan. No sect has a monopoly on it, and if ever we are to reach higher levels, if ever we are to realize the dreams inherent in all human breasts of

the establishment of a "Heaven" on earth, we must recognize that "all peoples were created in His image," and, therefore, have the same inalienable right to see the universe through their own eyes.

The scientist, as a rule, is a broad-minded, sympathetic person who is striving to drive out intolerance and make possible a greater degree of freedom of thought and action. He does not interfere with the dreams and aspirations of those who do not share his opinions, but he realizes that the greatest good can come only through the full expression of honest convictions. He is interested in firmly establishing truth, and by means of a free and liberal exchange of ideas in so influencing others that their notions will be either strengthened or modified in the right direction. He believes that nothing, even in religion, should be taken for granted. Since the dawn of civilization people have been struggling for a rational outlook and for a reasonable faith. Real religion should welcome new truths and modify its beliefs accordingly. Progress means the enlargement or modification of old notions through the discovery of new facts and principles. There was a time in history when people were persecuted, imprisoned, or cruelly tortured for holding opinions which are now universally accepted — and all in the name of religion. Today there are some zealots who would like to turn the hands of time backward and resurrect the torture, the horror, and the inquisition of the Dark Ages in order to accomplish their own purposes. What a sad commentary on the intelligence of the period in which we live!

At the time of the Scopes trial in Tennessee there

appeared in one of the issues of the Sunday *Times* of London the following scathing criticism of the present spirit in America:

Obscured by grotesque impediments of broadcasting, movies and other factors hardly making for dignity, with which Americans elect to invest their solemn official occasions, a principle of first importance stands involved, a principle on which the whole of progress depends, namely, the freedom of human thought. In the United States, liberty is a common word. It has generally been regarded there as a common possession. But what are we to think? Here is a school teacher of a modern republican country on trial by a state for the crime of teaching the theory of evolution. This is religious persecution of a kind with which Europe was more familiar in the Dark Ages. Americans, it seems, retain in their blood something of the bigotry of their Puritan ancestors.

Progress is not merely an affair of material things; it appears in mental and spiritual enlightenment. The new world has still something to learn from the old. Fortunately for humanity, no attempt to put back the clock can succeed. Faith cannot be protected by law nor propagated by force. What is done is done. Galileo stands despite the Inquisition, and Darwin stands, rage King Bryan Canute and his fundamentalists never so furiously. As for freedom of thought, enactments of man shall not prevail against it.

A sixth misconception often found to exist among unintelligent laymen is that evolutionists degrade man by holding that he is descended from the monkey. So universal is this belief that in many minds evolution is synonymous with "monkey descent." The fact is,

however, that no evolutionist teaches this, and for the simple reason that the facts do not warrant such a conclusion. No scientist denies that there is a very close kinship between apes and human beings, and that they have many common traits; but persons who have studied the problem agree that these groups are now quite divergent and separate, with numerous distinct variations which mark them off from one another. However, it must be pointed out that careful research on the fossil human and ape-like remains unearthed during the last hundred years in various parts of the world has led the evolutionist to the conviction that the higher apes and human beings which exist at present, and have existed in past generations, originated from some remote, pre-existing stock of mammals which possessed in common many of the distinctive characteristics of both. From this common ancestry, in due course of time, a monkey branch sprang, and through adaptation and specialization this branch has given origin to many of the existing types of higher apes. Likewise, the human stock arose as another distinct offshoot in a different direction, and from it have evolved the different human races which have successively populated the earth.

Such an interpretation is quite different from that often encountered among laymen, namely, that men are descended from monkeys. Human beings and apes have evolved side by side, each within their own sphere — all biologists, paleontologists, and ethnologists are agreed upon this fact. Furthermore, they are united in their conviction that men as well as monkeys hold a common relationship to the lower forms of animal life,

and that they have evolved by slow, imperceptible steps from and through these lower stages to their present levels. Men and apes are the most recent products in the evolutionary scheme of creation, and men have progressed very much farther than apes along certain lines of development. Judged by the advancement in intelligence, coördination, and social coöperation, modern man stands as the highest product of the evolutionary process. There is grandeur, beauty, and hope in this conception, uniting man with the forces of nature and making him an integral part of the unified scheme of natural law and order which is working out its harmonious plan throughout the universe.

The seventh and last misconception is that evolution is a false doctrine which is being abandoned by leading men of science throughout the world. No more infamous lie has ever been manufactured by ardent antagonists. There is not a reputable living scientist who does not accept the facts of evolution. At various times opponents of the doctrine have issued statements to the effect that the leaders in science are opposed to evolution, but in every such instance either the names were not given, or, when given, were recognized to be those of old scientists, such as Mivart or Agassiz, who have long been dead, or of men who have achieved no standing whatsoever in their chosen fields.

In the United States all scientists are as one in their acceptance of evolution. On numerous occasions the council of the American Association for the Advancement of Science (which organization has a present membership of some seventeen thousand and a roster of

close to ninety scientific societies, either directly affiliated or closely associated with it) has unanimously adopted resolutions affirming its faith in the doctrine of evolution, and emphasizing particularly that, "so far as the scientific evidences of the evolution of plants and animals and man are concerned, there is no ground whatever for the assertion that these evidences constitute a 'mere guess.' No scientific generalization is more strongly supported by thoroughly tested evidences than is that of organic evolution."

In closing this chapter, we may do well to reiterate that evolution is now firmly established, to such an extent that all science accepts it without question; but that in regard to the factors of evolution, there are numerous honest differences of opinion even among scientists. Because of this situation, many laymen have formulated the erroneous notion that there is, therefore, nothing to the evolutionary conception. All of the sciences — astronomy, geology, physics, chemistry, and biology — lend innumerable evidences in support of the doctrine. The inevitable conclusion is that in science all of the diverging highways of endeavor lead to but one goal — EVOLUTION.

CHAPTER III

INORGANIC EVOLUTION

As was pointed out in the first chapter, matter is regarded not only as the basis of the sciences, but also as the foundation for everything which constitutes nature. The objects which exist in space may be classified under either of two heads: non-living or living. The sciences dealing with non-living manifestations are commonly called inorganic, whereas those concerned with the living expressions of matter are grouped as organic. In line with this classification, evolution applied to the non-living world is termed inorganic evolution, and that applied to the living world is called organic evolution. Evolution is a continuous progression, and applies to the inorganic realm quite as much as to the organic. All nature, as it exists, is a manifestation of evolutionary forces, and the same immutable laws hold good for all expressions, whether they be animate or inanimate.

There was a time when science regarded non-living and living matter as two hard and fast units, with no intervening gradations or transitions. However, the discoveries of the last century have broken down the barriers, and although we now recognize these two classes by giving them distinct, superficial characteristics, we are nevertheless convinced that they are simply

different phases in the evolution of the same primary, fundamental stuff. The current belief is that inorganic evolution took place first and that gradually this paved the way for organic evolution.

This chapter deals with non-living or inorganic evolution, and the subject is discussed under three headings: first, cosmic evolution, or the evolution of our universe; second, atomic evolution, that is, the evolution of those foundation-stones of matter known as the chemical elements; and third, geologic evolution, or the formation of our own sphere, the earth, and its development to the stage when living objects made their appearance upon it.

1. Cosmic Evolution

Cosmic evolution deals with the origin and development of the universe, of which the earth is an integral part. In recent years the science of astronomy has made tremendous strides, and numerous discoveries have led scientists to the conclusion that in all probability our universe is only one of many similar universes which exist in the vast reaches of space (Figure 4). Undoubtedly our universe occupies a comparatively limited area; and beyond it, at incredible distances, are other so-called "island universes." The discovery of these "island universes" has been made possible largely through studies of the so-called "nebulæ" (Figures 4 and 9), a great number of which have been located and described. They will be discussed more fully when the question of the origin and evolution of the heavenly bodies is considered.

Inasmuch as our own universe is better known than the others, it will be well to confine our discussion to it. Our universe consists of the countless stars of varying magnitude and the smaller celestial bodies, which are revealed to us in our present position. Many stars, like

Yerkes Observatory Photo.

FIG. 4. THE DIFFUSE NORTH AMERICAN NEBULA

our own sun, in reality are centers of vast systems of smaller bodies which revolve around them. The astronomer considers a universe an immense collection of stellar systems, all close enough to control one another's movement by gravitational[1] forces. The system to

[1] "Gravity" is the name applied to the force of attraction that the particles of matter in space exert upon one another.

which we belong is called the "solar system" (Figure 5), and, as already intimated, it comprises a very insignificant part of our universe. At its center is the sun, which is a star of relatively small magnitude; and revolving around the sun, in sequence, are eight smaller bodies, the planets: Mercury, Venus, the Earth, Mars, Jupiter, Saturn, Uranus, and Neptune. The earth, which is the third planet from the sun, is approximately

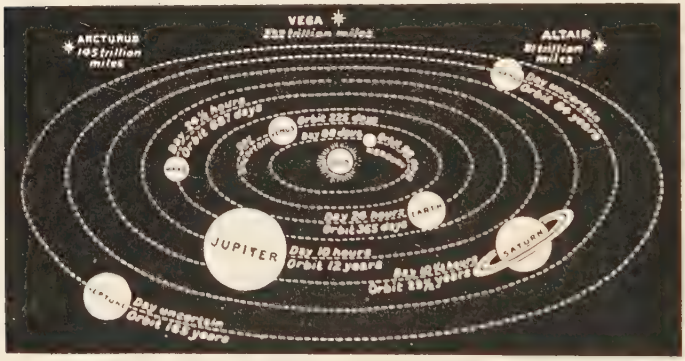


Fig. 5. The Solar System

(From J. Arthur Thomson, *The Outline of Science*, 1922. Courtesy of G. P. Putnam's Sons.)

92,830,000 miles distant from it. The first two planets are much nearer to the sun, whereas the last five are much further away.

Our universe is composed of countless similar systems, many of them mightier than our own. When a person gazes out at night and beholds the vast canopy of twinkling stars overhead, he has little conception of the enormous sizes of, or distances between, these

seemingly minute bodies. Only a few stars are smaller than the sun, and the vast majority of them are many, many times larger. When we compare the larger stars with terrestrial objects of known dimensions, we acquire some vague idea of their enormous mass. For instance, the diameter of the earth is approximately 7,918 miles, that of the sun is about 865,000 miles, whereas the diameter of one of the giant stars — Betelgeuse — has been estimated at 215,000,000 miles. Professor Eddington, the English astronomer, presented a vivid picture of the comparative volumes of these spheres when he asserted: "A million earths make one sun; ten million suns make one Betelgeuse." [2]

In regard to mass, careful computations by the best methods of science indicate that the earth weighs approximately six sextillion (6,000,000,000,000,000,000,000) tons; and the sun has been estimated to be about 332,000 times heavier than the earth. The relative masses of the giant stars are not accurately known, but they must be at least as great as, if not infinitely greater than, that of the sun.

At the present time astronomers have shown the existence of more than two hundred million stars, but this is a very small fraction of the number which are believed to exist. Although the exact figure is not known, estimates vary from two hundred million to forty billion. Dr. Abbot [3] of the Smithsonian Institution asserts

[2] "The Interior of a Star," *Scientific Monthly*, vol. 17 (1923), pp. 250–270.

[3] "Where are the Stars?" *Scientific Monthly*, vol. 20 (1915), pp. 616–620.

that with the naked eye one can see no more than three or four thousand stars; but with the aid of a powerful telescope, the astronomer can discern between thirty and forty million. Most astronomers believe that there must be about one billion stars distributed in space at various distances from the earth. The magnitude of this fact can be appreciated when it is recognized that only about thirty stars are located within a radius of a hundred trillion (100,000,000,000,000) miles from our earth, and only a few hundred within the radius of five hundred trillion miles. The more distant stars of the Milky Way are estimated to be nearly one hundred thousand trillion miles from the earth.

How large is our own universe? According to the American astronomer Campbell:

> The universe of stars — our stellar system — is believed by astronomers to occupy a limited volume of space that is somewhat the shape of a very flat pocket watch; more strictly, a much flattened ellipsoid or spheroid. It is not intended to convey the impression that the boundaries of the stellar system are sharply defined, nor that the stars are uniformly distributed throughout a volume of space roughly ellipsoidal in form. The thinning-out of stars near the confines of the system may be both gradual and irregular. The equatorial plane of the ellipsoid is coincident with the central plane of the Milky Way. We see the Milky Way, or Galaxy, as a bright band encircling the sky, because looking toward the Galaxy we are looking out through the greatest depth of stars. There remains considerable uncertainty as to the dimensions of the system, chiefly for two reasons: first, the stars near the surface of the ellipsoid are everywhere too far

away to let us measure their distances; and secondly, the system may be considerably larger than it seems because of possible obstruction of starlight in its passage through space. Newcomb has suggested that the shorter radius of the system, at right angles to the plane of the Galaxy, may be taken as of the order of three thousand light-years.[1] The long radii, those in the plane of the Milky Way, may be at least ten times as great; that is, thirty thousand light-years, or more. . . . Our solar system is believed to be somewhere near the center of the stellar system; the counts of stars in all parts of the sky do not indicate that any one section of the Milky Way structure is appreciably closer to us, so to speak, than any other sections of it.[5]

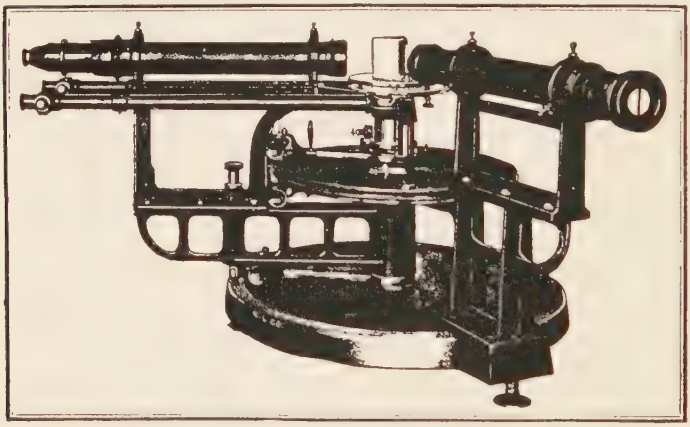
There has been considerable controversy concerning the nature of the stars, but the best opinion regards them as luminous bodies which emit light similar to that given off by our own sun. Like the sun, they are considered to be huge combinations of intensely hot gaseous vapors and metals. They are moving at tremendous rates of speed, some of them many times faster than the earth itself, which is known to revolve around the sun at the rate of more than a thousand miles a minute. In a word, the stars must be regarded as great balls of fire, possessing inconceivably high temperatures and moving at indescribable velocities.

By the aid of a unique instrument known as the

[4] Light travels at the rate of about 186,000 miles a second. A light-year, therefore, represents the distance traversed by a ray of light in one year.

[5] "The Nebulæ," *Science*, Illustrated Supplement, vol. 45 (1917), no. 1169.

"spectroscope" (Figure 6), the astronomer has been enabled to discover a great many facts concerning the stars, such as their chemical composition, the intensity of the light which they emit, their approximate temperatures, whether they are gaseous, liquid, or solid, and their sequence of evolution. The spectroscope is equipped with a prism of glass that is capable of breaking the light emitted from a glowing object into its com-



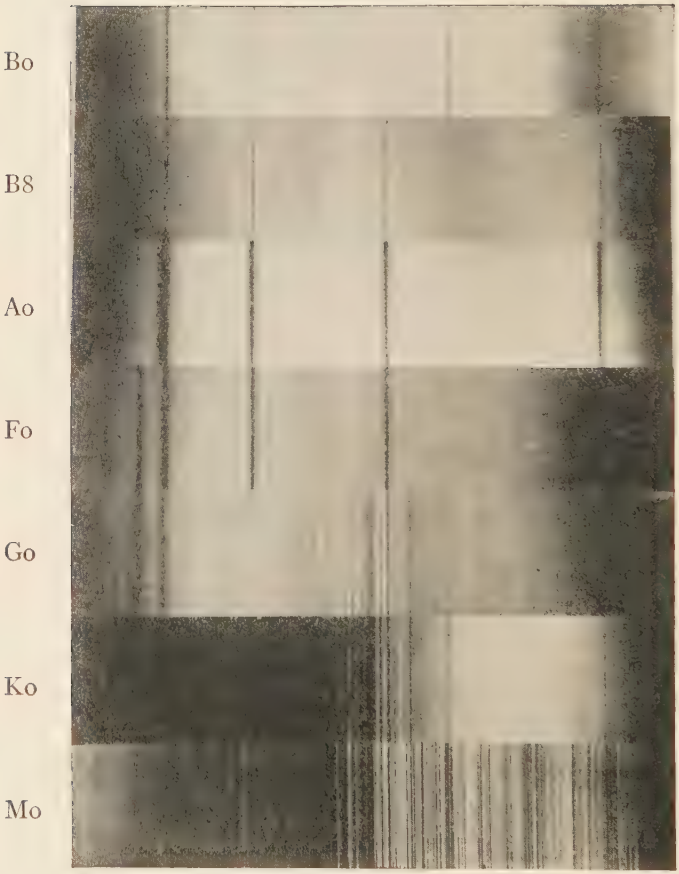
Courtesy of Spencer Lens Co.

FIG. 6. A SPECTROSCOPE

ponent colors, collectively called "spectrum." The spectrum of sunlight gives the typical rainbow effect familiar to everybody. The fact is that when any chemical substance which has been heated to the glowing point is studied with the spectroscope, it is found to give a typical spectrum. Furthermore, if a cooler mass of the same substance be placed between it and the spectroscope, dark bands will appear in those places of the

spectrum where the characteristic colors originally made their appearance. This has been interpreted to mean that the cooler substance absorbs its own color rays, thereby preventing their appearance in the spectrum. Also, it has been definitely established that all of the various chemical elements in existence, when made to glow, possess distinctive line spectra, and that no two of these are ever alike. Such facts have been extremely helpful in enabling the astronomer to determine exactly what chemical elements exist in the distant stars. Figure 7 shows various types of stellar spectra.

Moreover, the spectroscope intimates that the stars are undergoing an evolution, the various stages of which are revealed by their color, and more particularly by the chemical elements discovered in them. Until a few years ago it was thought that the youngest stars were the intensely white ones, and that these, with age, would gradually shade into whitish-blue, blue, orange, red, and dull-red. More recent discoveries, however, have shown the existence of two kinds of red stars, very large ones called "giant reds," and much smaller ones known as "dwarf reds." Careful spectroscopic research has revealed that the former are undoubtedly the younger stars, whereas the latter are the older ones. It is now thought that a star, when it is first formed, consists of a diffuse mass of gas that does not possess a great deal of heat; and in this stage it glows with a dull-red tinge. As it contracts it becomes not only hotter, but denser; and at the same time its color changes consecutively to orange, yellow, white, and blue. In this last condition — namely, the bluish stage — its temperature has



Harvard College Observatory Photo.

FIG. 7. TYPICAL STELLAR SPECTRA

The typical stars and their temperatures are: Bo, Epsilon Orionis, 20,000° C; B8, Rigel, 13,500° C; Ao, Sirius, 10,000° C; Fo, Canopus, 7,000° C; Go, Capella, 5,600° C; Ko, Arcturus, 4,500° C; Mo, Betelgeuse, 3,500° C.

reached the maximum and it then begins to cool and decline. However, contraction of the mass continues, and the color changes take place in the inverse order of white, yellow, orange, and dull-red. All this is quite similar to what occurs in a piece of metal that has been heated to the glowing point and then allowed to cool. What follows the dwarf dull-red stage of the star is mere conjecture, but many astronomers think that there are two final steps: the star declines to the condition represented by the so-called "variable stars," in which light is sent out intermittently; and then it loses its luminosity entirely and becomes a completely cold, dark, and invisible body. The sun is looked upon as a star which is in its middle age, and more than forty elements have already been shown to exist in it.

The foregoing description gives some idea of what we mean when we speak of "our universe." It consists of a great many stellar systems like our own, which is insignificant in comparison, all of them located at great distances from the earth and from one another. Is the space between them empty, or is it filled with something? A definite answer is impossible, but recent discoveries relating to the constitution of matter indicate that all of this space contains a substance called "luminiferous ether." Its composition is unknown, but it is looked upon as non-particulate pre-matter in a diffused state, out of which particulate, ponderable matter is formed through the agency of energy. The stars that stud the sky are, in reality, the centers of the systems of our universe. They are regarded by modern

astronomers as terrifically hot and luminous globes undergoing such tremendous transformations that large numbers of the smallest divisible particles of matter, known as "electrons," are continuously being discharged from them into space. We shall have more to say concerning electrons and luminiferous ether when we come to consider atomic evolution.

The dynamic, new conception of the universe is that nothing is stable, that everything is in motion and undergoing transformation. The old conception, on the other hand, regarded the universe as static, stable, and definitely confined. Heaven was looked upon as a vast, concave dome resting securely on the highest mountain peaks which towered up from the surface of the earth. The sun and moon made daily excursions across the dome, while the stars were lights, similar to lanterns, which shone through distinct openings in "Heaven." The earth itself was believed to be flat, extending to definitely confined limits beyond which there was a bottomless abyss (Figure 8). All such ideas have been crushed by the weight of newer knowledge.

Many astronomers, as has been said, are convinced that there are other universes similar to our own. They have reached this conclusion through the study of the so-called "nebulæ." Literally translated, the word "nebula" means fog, mist, vapor, or cloud; and in astronomy, therefore, "nebulæ" are fog-like or cloud-like structures which exist in space. Two kinds have been discovered: one (Figure 4) is diffuse, gaseous, and nearly always luminous, stretching over such tremendous distances that our own solar system becomes

insignificant beside it; the other (Figure 9), in the form of a spiral, has a dense mass at the center, from which radiate numerous luminous arms possessing large knots of condensed material. It is believed that the spiral nebulæ have been derived from the diffuse nebulæ

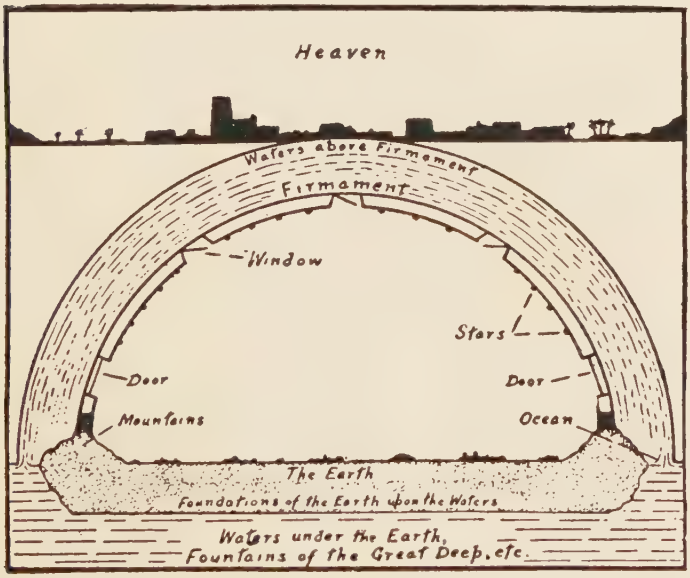


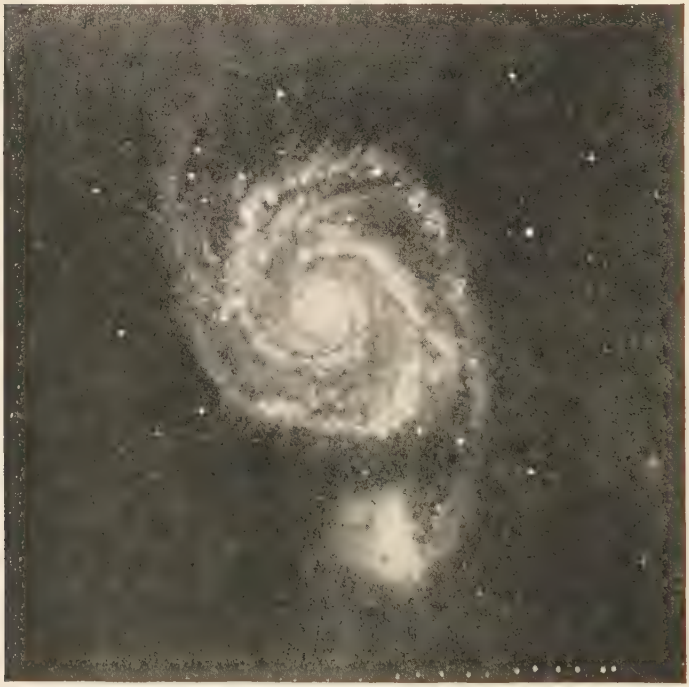
FIG. 8. THE HEBREW-CHALDEAN CONCEPT OF THE UNIVERSE

(From Curtis, *Science and Human Affairs*. Courtesy of Harcourt, Brace & Co.)

through a process of condensation, and that probably they are composed of a combination of incandescent gases, liquids, and solids.

Thus far astronomy has shown the existence of more than a half-million nebulæ in all stages of transition, most of them being of the spiral type, but this number

constantly grows larger as more powerful telescopes and other astronomical instruments are perfected. The number of nebulæ in space may be conservatively estimated at about a million, most of which, in the light of what is already known, must be of the spiral kind.



Lick Observatory Photo.

FIG. 9. SPIRAL NEBULA

The spectroscope reveals much regarding the composition of the nebulæ. The diffuse type is discovered to be of a gaseous nature, composed largely of helium, hydrogen, and nebulium. The latter is the lightest of

these three gases, and until the present time none of it has been found on the earth. When a spiral nebula is examined with the spectroscope, a complicated spectrum is observed, indicating the presence of nearly all of the elements found on the earth. Incidentally, it distinctly shows that the spiral nebulæ are combinations of gases, liquids, and solids.

The prevalent opinion is that the spiral nebulæ are other starry systems or universes similar to our own. Joseph McCabe graphically describes them as follows:

> These spiral nebulæ, of which we know more than half a million, if not a million, are supposed by many astronomers to be vast systems of stars separated by incalculable abysses of empty space from the system of stars to which our sun belongs. From them our colossal universe would be seen as a small spiral nebula, shining so faintly in the heavens that it might not be visible to the unaided eye. They are all " island universes." [6]

The natural question is: how did the nebulæ originate? There is no positive answer, but various conceptions have been formulated. The best scientific opinion regards them as having developed in either of two ways: as accumulations and condensations of the tremendous quantities of free electrons which are being constantly discharged from active, luminous bodies such as the stars, or as the resultant products of terrific collisions between old celestial bodies. Astronomers are certain that there are many such bodies in space, and that if two of them were to collide the force of the impact

[6] *The Wonders of the Stars,* New York, Putnam, 1923, p. 79.

would be sufficient to transform both of them into a thin, incandescent vapor or nebula. This nebula then begins its evolution. Its temperature increases, and at the same time gravitational forces so act upon it that it starts to rotate. Gradually it assumes the appearance of a spiral nebula, with radiating arms along which denser knots have formed. The latter are regarded either as independent stars or as clusters of stars. Through the continued action of the agencies of contraction and condensation these stars acquire greater definition, with the result that a complete stellar system is produced. Our own universe is thought to have originated in somewhat similar fashion.

How the planets and other bodies that are often found revolving around a star, constituting a system similar to our own solar system, came into being, is another question upon which there is considerable disagreement. Until comparatively recent years the best explanation for the origin of the solar system was the "nebular hypothesis" propounded by Kant and Laplace in the second half of the eighteenth century. According to this theory, the sun, together with its planets, satellites, and other bodies, was produced from an independent nebula which at first was diffuse and later became spiral, possessing huge radiating arms along which larger masses could be distinguished. This spiral nebula was incandescent and extremely hot. By cooling and contraction, the larger and smaller masses along the radiating arms condensed into the planets or smaller bodies, leaving the huge central mass of the nebula as the sun.

During the last thirty years Chamberlin and Moulton have proposed the "planetesimal hypothesis" of the development of the solar system. They regard the planets and other bodies of this system as the result of the accumulation and amalgamation of large numbers of minute swarming particles, each of which rotates elliptically around a central nucleus, the whole system closely resembling a spiral nebula. This swarming material was produced when our sun and some other star approached each other rather closely. Violent waves were set in motion on the surfaces of both celestial spheres, with the result that tremendous particles of matter were flung into space. Some of these particles undoubtedly were shot beyond range of the sun's zone of influence, but most of them remained within it and came directly under its control. After the colliding star had passed to other regions, the sun was left with large numbers of moving particles of matter in a gaseous, liquid, or solid state, each revolving in its own path around the sun. These so-called "planetesimals" became so numerous that they collided, crossed, and interfered with one another to such an extent that the larger masses absorbed the smaller ones, thereby producing the planets and other bodies of the solar system. This view considers the planets as having always been solid bodies, never so hot as to be incandescent and molten.

Campbell and others reject both the nebular and the planetesimal hypotheses as explanations of the origin of our solar system. Campbell's view is best given in his own words:

I think it is more probable that our stellar system as a whole is a spiral nebula, and that our solar system has been formed from an insignificant detail of spiral structure, than that our sun and its system of planets and moons should be the evolved product of an entire spiral nebula. Of course we have not the proof of this; but the chances would appear to be strong that the ancestor of our solar system was a mass, nebulous or otherwise, comparatively diminutive in size.[7]

Notwithstanding these diversities of opinion about details, all astronomers are united in their faith in the evolution of the various systems of our universe — in fact, in the evolution of all of the many universes which may exist. Starting with the luminiferous ether and the energized particles, the electrons, they can vision the orderly development of all of the mighty systems which pervade space. The various steps in this evolutionary process have been discovered in the numerous nebulæ, stars, and other heavenly bodies which astronomy has thus far described. No one is prepared to say what the ether or energized particles within it are; but it seems quite certain that they exist and that under the right conditions they aggregate and account for the various stellar systems of space. Science has no definite explanation for what is beyond or behind the ether, and so long as this remains true the individual observer may, if he so desires, postulate an answer to suit himself.

[7] Campbell, *op. cit.*

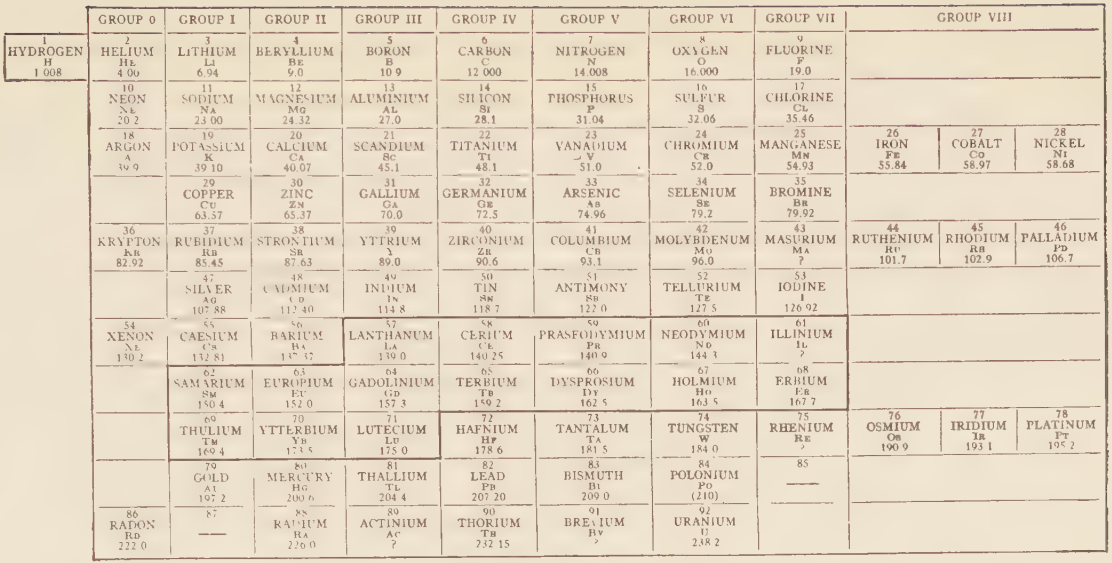
2. Atomic Evolution

Atomic evolution deals with the origin and development of the various foundation stones of chemistry, technically called "elements." The chemist has discovered about ninety elements, which are found to be basic to all of the material things with which we are familiar. Historically, our ideas regarding the elements have undergone many changes. Before chemistry was developed as an exact science there existed crude alchemy, the main object of which was to discover some "philosopher's stone" by means of which crude metals might be transformed into pure gold. This soon gave way to the chemistry of the eighteenth and nineteenth centuries, and the search for the philosopher's stone was abandoned as futile. Chemists laughed at the notion and termed it impossible. They then became actively engaged in discovering and describing new elements, with the result that stability set in and the idea of the fixity of the elements gradually developed. These came to be regarded as separate and distinct entities, with no transitions between them. Each element was considered to be composed of a group of smaller particles termed "atoms," and each element was distinguished from another by its atomic weight (which in every instance is the atomic weight of the individual element as compared with the standard atomic weight of hydrogen, which is almost exactly one); this was not interpreted as an indication of identity but rather as one of distinctness.

The atom was conceived to be the smallest particle

of matter, beyond which science could not penetrate. With the discovery of radio-active substances in 1896, and particularly of radium in 1898, it became necessary to modify all of the old ideas of fixity. Modern chemists became alchemists of a new type, searching not alone for the single agent that could transform crude metal into gold, but for the means by which the known elements could be produced from some primal stuff basic to them all.

Some time prior to the discovery of radio-active substances, chemists had noticed that when the elements were arranged in sequence, according to their atomic weights, a regular, fluctuating, and logical periodicity could be detected among them. Furthermore, it was observed that they could be organized into a number of definite horizontal series, each of which possessed similar characteristics. Vertically, the elements fell into groups which also were found to have a striking relationship. These facts led chemists such as Mendeléeff and Meyer to the discovery of the so-called "periodic system" of classifying the elements into a table according to their atomic weights and according to the similarity of their properties (Figure 10). A careful examination of the table revealed numerous blank spaces where, logically, elements should have appeared; and slowly the idea forced itself upon chemists that these spaces indicated elements which had not yet been discovered. Moreover, the periodic table made it possible, through a knowledge of the other elements in the particular series, to predict the atomic weights and properties of the unknown elements. When these were finally dis-



	GROUP 0	GROUP I	GROUP II	GROUP III	GROUP IV	GROUP V	GROUP VI	GROUP VII	GROUP VIII		
1 HYDROGEN H 1 008	2 HELIUM He 4 00	3 LITHIUM Li 6.94	4 BERYLLIUM Be 9.0	5 BORON B 10 9	6 CARBON C 12 000	7 NITROGEN N 14.008	8 OXYGEN O 16.000	9 FLUORINE F 19.0			
	10 NEON Ne 20 2	11 SODIUM Na 23 00	12 MAGNESIUM Mg 24.32	13 ALUMINIUM Al 27.0	14 SILICON Si 28.1	15 PHOSPHORUS P 31.04	16 SULFUR S 32.06	17 CHLORINE Cl 35.46			
	18 ARGON A 39 9	19 POTASSIUM K 39 10	20 CALCIUM Ca 40.07	21 SCANDIUM Sc 45.1	22 TITANIUM Ti 48.1	23 VANADIUM V 51.0	24 CHROMIUM Cr 52.0	25 MANGANESE Mn 54.93	26 IRON Fe 55.84	27 COBALT Co 58.97	28 NICKEL Ni 58.68
		29 COPPER Cu 63.57	30 ZINC Zn 65.37	31 GALLIUM Ga 70.0	32 GERMANIUM Ge 72.5	33 ARSENIC As 74.96	34 SELENIUM Se 79.2	35 BROMINE Br 79.92			
	36 KRYPTON Kr 82.92	37 RUBIDIUM Rb 85.45	38 STRONTIUM Sr 87.63	39 YTTRIUM Y 89.0	40 ZIRCONIUM Zr 90.6	41 COLUMBIUM Cb 93.1	42 MOLYBDENUM Mo 96.0	43 MASURIUM Ma ?	44 RUTHENIUM Ru 101.7	45 RHODIUM Rh 102.9	46 PALLADIUM Pd 106.7
		47 SILVER Ag 107 88	48 CADMIUM Cd 112 40	49 INDIUM In 114 8	50 TIN Sn 118 7	51 ANTIMONY Sb 122 0	52 TELLURIUM Te 127.5	53 IODINE I 126 92			
	54 XENON Xe 130 2	55 CAESIUM Cs 132 81	56 BARIUM Ba 137 37	57 LANTHANUM La 139 0	58 CERIUM Ce 140 25	59 PRASEODYMIUM Pr 140 9	60 NEODYMIUM Nd 144 3	61 ILLINIUM Il ?			
		62 SAMARIUM Sm 150 4	63 EUROPIUM Eu 152 0	64 GADOLINIUM Gd 157 3	65 TERBIUM Tb 159 2	66 DYSPROSIUM Dy 162 5	67 HOLMIUM Ho 163 5	68 ERBIUM Er 167 7			
		69 THULIUM Tm 169 4	70 YTTERBIUM Yb 173 5	71 LUTECIUM Lu 175 0	72 HAFNIUM Hf 178 6	73 TANTALUM Ta 181 5	74 TUNGSTEN W 184 0	75 RHENIUM Re ?	76 OSMIUM Os 190 9	77 IRIDIUM Ir 193 1	78 PLATINUM Pt 195 2
		79 GOLD Au 197 2	80 MERCURY Hg 200 6	81 THALLIUM Tl 204 4	82 LEAD Pb 207 20	83 BISMUTH Bi 209 0	84 POLONIUM Po (210)	85 ——			
	86 RADON Rd 222 0	87 ——	88 RADIUM Ra 226 0	89 ACTINIUM Ac ?	90 THORIUM Th 232 15	91 BREVIUM Bv ?	92 URANIUM U 238 2				

FIG. 10. PERIODIC TABLE OF THE ELEMENTS

Atomic weights are indicated below, and atomic numbers above, the elements. Note that the elements from 57 through 71 belong to the same family in Group III. (From Mayer, *The Seven Seals of Science*. Courtesy of The Century Co.)

covered, the remarkable fact was that in every instance they fully substantiated the predictions in regard to them.

Perhaps the most important generalization to which the periodic table gave rise was one to the effect that some identity existed between the series and groups of elements, similar to that found among the units of the plant and animal kingdoms: namely, identity which bespeaks a common origin and evolution from some fundamental stuff. This view has been materially strengthened and intensified by the research on radio-active substances. Incidentally, it has led to a new conception of the constitution of matter.

As already mentioned, our knowledge of radio-active substances is comparatively recent, dating from the year 1896. By a radio-active substance is meant one that is spontaneously undergoing disintegration and giving off certain emanations which, under the right conditions, accumulate to form substances different from that from which they were liberated. In every case these newly-formed structures have been discovered to be less complex than those from which they were derived. Thus far, more than forty elements have been found to possess radio-activity, but many scientists are of the opinion that all of the elements may be radio-active.

When a radio-active substance such as radium or uranium is studied, it is found to be emitting radiations of three kinds called, respectively, the alpha, beta, and gamma rays. The alpha and beta rays have been investigated at considerable length, and have been found to consist of extremely minute particles, the size, mass,

and energy content of which have been accurately determined. The gamma rays, on the other hand, are not particles at all; they are mere pulsations or waves within the ether — that is, ethereal radiations which have been shown to be closely related to, if not identical with, the so-called "X-rays."

The beta particle is considerably smaller than the alpha particle and has a mass equal to about one eighteen-hundredth of an atom of hydrogen. The speed at which it travels is nearly that of light — about 186,000 miles a second. The beta particles have proved to be identical with the smallest particles of matter which bear electricity, and therefore have been called "electrons." An electric current really is due to many millions of these electrons or beta particles traveling along a wire.

The alpha particle is more massive than the beta particle, having about twice the charge and four times the mass of an atom of hydrogen. It is a veritable giant as compared with the beta particle, and possesses the most concentrated source of energy now available. Furthermore, it carries a positive charge of electricity, whereas the beta particle carries a negative charge. This means that these two particles are deflected in different directions by magnets or electrically charged bodies. In spite of the fact that the alpha particle is many times larger in size and energy content than the beta particle, its penetrating powers are considerably less than those of the latter. When the alpha particle comes in contact with some solid object such as aluminum, it penetrates a short distance, loses its electrical

charge, and becomes transformed into an atom of helium, one of the inert gases recently discovered. Here helium is manufactured spontaneously before our very eyes. The assertion has been made that an atom of helium may be produced synthetically from four atoms of hydrogen, and it is now believed, therefore, that these two elements are quite similar. When we follow all of the transformations in a radio-active substance, such as uranium, we find a remarkable evolution occurring before us. In logical sequence, radium, numerous intermediate products, and finally lead are formed.

Basing their conclusions on such studies as those briefly outlined above, chemists and physicists have modified their former theories as to the fixity of the elements, and have formulated the conception of a gradual and progressive evolution of all of the elements from some primal substance. This view is now established as firmly as that of the evolution of plants and animals. The atom of an element is no longer looked upon as an indivisible entity, but rather as an electrical system of finely divided particles of positive and negative electricity. At the center of such a system is a compact nucleus and around it revolve the electrons or beta particles carrying charges of negative electricity. The nucleus itself consists of two entities: particles of hydrogen bearing charges of positive electricity, called "protons," and the negatively charged electrons. Through various combinations of protons and electrons the different elements may be constructed.

Professor Herbert Dingle aptly summarizes the new view of matter when he says:

The atom is represented as something like a miniature solar system. The central nucleus, or "Sun," of the system consists of a quantity of electricity having a net positive charge. Corresponding to the planets, there are a number of revolving "electrons," or unit negative electric charges, just sufficient to balance the positive charge of the nucleus and make the atom, as a whole, electrically neutral. The spatial dimensions of the nucleus are negligible, but its mass is almost equal to that of the whole atom, the mass of the electrons being comparatively of little account. One element is distinguished from another merely by the amount of the charge of the nucleus — and, as a consequence, by the number of revolving electrons and the mass of the atom, since mass, according to modern ideas, depends entirely on electromagnetic condition. Hydrogen, the lightest element known, is believed to have a unit positive charge as the nucleus, and one electron in revolution round it. Helium, the next element in order of weight, has two net positive charges and two revolving electrons; and so on, an increase of one unit in "atomic number," as the number of electrons is called, marking an advance from one element to the next in the periodic table of chemical elements.[8]

The electrons are now considered to be the most finely divisible particles of matter. Sir J. J. Thomson, the discoverer of electrons, makes the following assertions in regard to them:

Electrons are particles of exceedingly small mass carrying a charge of negative electricity; there is only one kind of electron, for all electrons have the same mass and carry the same electric charge. Until the discovery in 1897 of the

[8] *Modern Astrophysics.* Coypright 1924 by The MacMillan Company. p. 18. Reprinted by permission of the publishers.

electron, the smallest mass known to science was that of an atom of the lightest element, hydrogen, but the mass of this atom is 1800 times greater than that of an electron. The mass of an electron is by far the smallest of all known masses. The electrons are the bricks which build up the atom; an atom of hydrogen contains one electron, an atom of oxygen eight, one of lead about one hundred, and so on. Differences in the number and arrangement of the electrons in the atom are supposed to account for the difference in the properties of the atoms of the different chemical elements.[9]

We do not know what comes before electrons, but we are certain that there must be something which as yet has not lent itself to analysis. Hence physicists, chemists, and astronomers have postulated the existence of " luminiferous ether " which pervades all space. This has been termed " proto-matter," out of which actual matter is formed. Scientists assert that the synthesis of matter has occurred somewhat as follows: from condensations of the luminiferous ether, through the agency of energy, first electrons, then atoms, then molecules, and finally the elements themselves were formed. The compounds are nothing more than combinations of different elements. Sir Ernest Rutherford, in an address entitled " The Natural and Artificial Disintegration of the Elements," delivered in 1924 at the centenary celebration of the Franklin Institute of Philadelphia, graphically described the evolution of the elements in the following words:

In considering the origin of the elements, we may for simplicity suppose a large diffused mass of hydrogen which is

[9] " The Electron," *Scientific Monthly*, vol. 20 (1925), pp. 113–115.

gradually heated by its gravitational condensation. At high temperatures the gas would consist mainly of free hydrogen nuclei and electrons, and some of these would in course of time combine to form neutrons,[10] emitting energy in the process. These neutrons would collect together in nuclear masses of all kinds of complexity. Now the tendency of the groups of neutrons would be to form more stable nuclear combinations, such as helium nuclei of mass four, and possibly intermediate stages of mass two and three. Energy would be emitted in these processes probably in the form of swift surplus electrons which were not necessary for the stability of the system. In a sense, all these nuclear masses would be radio-active, but some of them in their transformations may reach a stable configuration which would represent the nucleus of one of our surviving elements. If we suppose that nuclear masses over a wide range of mass can be formed before serious transformation occurs, it is easy to see how every possible type of stable element will gradually emerge.[11]

Is it possible, then, that the alchemist's ancient dream of transforming baser metals into gold now will be realized? The discoveries in the realm of radio-activity make it certain that such a transformation will be a relatively simple matter. Already there have been reports that gold has been produced from lead and mercury, and there have also been rumors that other precious metals, such as silver and platinum, have been created in similar fashion. In the light of these discoveries it is no idle prediction to state that some day

[10] Rutherford has coined the term "neutron" to signify the close combination of a proton and an electron.

[11] *Scientific Monthly,* vol. 19 (1924), pp. 561–578.

we shall be able to synthesize the precious metals and probably all of the other elements from very crude material. Dr. Paul D. Foote says: "When the scientist is able to utilize an electric field of ten million volts, there is small doubt but that every element may be produced by transmutation." [12]

This is inorganic evolution and occurs before our eyes. Just as the old naturalists regarded organic species, so the old chemists regarded the inorganic elements, as separate and distinct entities, definitely established at the time of their first creation and since then remaining unchanged. But the disclosures of the last thirty years, resulting from the research upon radio-active substances, have definitely shown that the elements are not fixed; that they are disintegrating and undergoing transformations, with the result that they are spontaneously giving origin to different structures. In a word, we are witnessing the evolution of the elements, one from another.

3. Geologic Evolution

Geologic evolution is concerned with the origin of the earth and its development to its present form. As indicated in the section on Cosmic Evolution, the two most important conceptions which have been put forth to account for the earth are the Kant-Laplace nebular hypothesis and the Chamberlin-Moulton planetesimal theory.

[12] "The Alchemist," *Scientific Monthly*, vol. 19 (1924), pp. 239–262.

The former view postulates that the system of which the earth is a part was at first extremely hot and molten, and arranged as a spiral nebula. Through contraction and condensation the larger and smaller nebulous masses assumed definite form and became the planets and other bodies which now can be recognized in our solar system. This hypothesis held sway from the middle of the eighteenth century to almost the end of the nineteenth century, and it is still very popular with a large majority of geologists, astronomers, and educated people in general. Its adherents are of the opinion that the earth, in its evolution, has undergone seven stages or *eons,* each covering a period of many million years.

The first is the *nebular eon,* during which the earth was an intensely hot, incandescent, and gaseous mass, still attached to the original spiral nebula from which all of the other bodies constituting the solar system have developed.

The second is the *astral eon,* in which the first condensation took place. The earth then appeared like the sun, unbelievably hot, glowing, and molten. It is believed that at this time the moon was formed from a detached portion of the earth's outer surface.

The third stage is the *lithic eon,* in which the earth had cooled sufficiently to allow the formation of a thin exterior crust enclosing the hot, molten material in the interior. The earth was very hot at this time, much hotter, indeed, than anything that we can imagine. Most authorities believe that it possessed a temperature of approximately 2500° C.

Next, the fourth stage, called the *atmospheric eon,* set

in. During this period the heavy metals near the surface sank to the interior central recesses where they are found today, whereas the lighter materials and vapors emerged to the upper layers. In all probability gases escaped and formed a dense envelope around the outside, thereby forming the atmosphere. Geologists think that this atmosphere contained very little oxygen but was rich in water vapor, carbon dioxide, carbon monoxide, chlorine, hydrochloric acid, hydrogen, and some nitrogen.

The fifth stage, the *volcanic eon,* was a period of tremendous disturbances. It was characterized by terrific eruptions of hot molten materials from the depths of the earth, and these flowed out over the external surface where they solidified to form some of the existing mountain ranges. We can form some idea of the action which occurred during this eon when we study those regions of our planet in which active volcanoes now exist.

The sixth stage is the *hydrospheric eon,* in which the waters were formed. It must be remembered that wherever there is intense heat and action tremendous energy is always released in the form of vaporized gases. As cooling took place, a precipitation of the vapors occurred, resulting in the formation of large quantities of water. These filled in the low, hollow places and produced the various oceans. Since the earth was still extremely hot, these waters possessed a very high temperature, and violent chemical action was doubtless occurring within them.

The seventh and last stage is spoken of as the *sedi-*

mentary eon, the period in which the earth reached stability. The lithosphere (land), hydrosphere (water), and atmosphere (air) were definitely formed, making the earth ready for animal and plant life.

The advocates of the planetesimal theory, on the other hand, believe that planets like our earth were never extremely hot or molten. They hold that they were originally cold spheres, formed through an accumulation and combination of innumerable minute particles of nebulous matter, the so-called planetesimals, which swarmed and revolved in orbits around larger central nuclei of nebulous knots. Each of these knots attracted and combined with the smaller planetesimals, resulting in compact planets or bodies of lesser magnitude. Although the earth, as a whole, is supposed always to have remained solid, the expounders of this theory believe that liquefaction did occur in various scattered locations, resulting either from radio-activity or from the tremendous pressure exerted by the outer layers on the central interior.

Professor Osborn describes this theory as follows:

> According to the planetesimal theory, as set forth by Chamberlin, the earth, instead of consisting of a primitive molten globe as postulated by the old nebular hypothesis of Laplace, originated in a nebulous knot of solid matter as a nucleus of growth which was fed by the infall or accretion of scattered nebulous matter (planetesimals) coming within the sphere of control of this knot. The temperature of these accretions to the early earth could scarcely have been high, and the mode of addition of these planetesimals one by one explains the very heterogeneous matter and differentiated

specific gravity of the continents and oceanic basins. The present form of the earth's surface is the result of the combined action of the lithosphere (the rocks), hydrosphere (the water) and atmosphere (the air). Liquefaction of the rocks occurred locally and occasionally as the result of heat generated by increased pressure and by radio-activity; but the planetesimal hypothesis assumes that the present elastic rigid condition of the earth prevailed — at least in its outer half — throughout the history of its growth from the small original nebular knot to its present proportions and caused the permanence of its continents and of its oceanic basins. We are thus brought to conditions that are fundamental to the evolution of life on the earth.[13]

A number of scientists, while they accept the major features of the Chamberlin-Moulton hypothesis, are nevertheless opposed to the idea that the earth was built up as a solid body. Rather, they accept the view of Professor Barrell,[14] who believes that through the rapid infall of the planetesimals, and particularly the planetoids, our earth grew larger and at the same time became hotter. When it had reached its maximum size, the heat was so intense that most of its exterior mass, comprising the outer quarter of its radius, was in a completely molten condition. As cooling took place, the lithosphere, hydrosphere, and atmosphere made their appearance.

It has always been exceedingly interesting to inquire how long it took the earth to reach its present stage of

[13] *The Origin and Evolution of Life,* New York, Scribner, 1917, pp. 25–26.

[14] "The Origin of the Earth," *The Evolution of the Earth,* Lull (editor), New Haven, Yale University Press, 1918, chapter I.

evolution. There have been various estimates, ranging from as low as three million years to as high as one billion six hundred million years. In all cases these figures refer to the age of the earth since it cooled, and no one is prepared to say how long our planet existed before that time. Prior to the discovery of radio-active substances, all estimates of the age of the earth were based on such factors as the time required for the deposit of sediments in the oceans, the quantity of salts carried by the various waters of the hydrosphere, and the thicknesses of the different strata of rocks. Depending on such computations, geologists have conservatively calculated that the earth must be at least one hundred million years old. Since the discovery of radio-activity, however, scientists have considerably modified their beliefs, and they now attribute a far greater age to our planet than is revealed by any of the geological studies that have been mentioned.

The present method of computing the earth's age is based on the amount of lead discovered in the rocks of the earth's crust as compared with the amount of radio-active substances found in them. Persons who are familiar with the radio-active substances know that spontaneously they are constantly giving off atoms of helium and other materials which gradually change into lead. For instance, when a uranium atom throws off eight atoms of helium it becomes lead; similarly, when a thorium atom throws off six atoms of helium the resulting product is lead. It is, therefore, a simple matter to calculate the number of helium atoms thrown off from a radio-active substance in a given length of

time, and thereby determine the amount of lead produced during a year. By computing the relative quantities of lead and radio-active substance in minerals, it becomes possible accurately to measure the age of the rocks.

Some time ago the National Research Council of the United States appointed a committee to investigate this matter; working under the chairmanship of Professor A. C. Lane of Tufts College, the committee has found that some of the minerals from certain regions of Canada have reached an age of at least one billion two hundred and fifty million years. Later research undoubtedly will indicate how far back toward the beginning of our planet this age goes. Most scientists believe that the earth is considerably older than any of these estimates would indicate.

Before closing this chapter we may do well briefly to summarize the logical steps in inorganic evolution. The start is made with ether, which fills all space and is not perceptible to the senses. Within it are found great swarms of energized particles, the electrons and protons, which move at inconceivable velocities and bear opposite charges of electricity. Under suitable conditions of energy these particles combine in various ways; and thus all of the chemical elements, all of the stars, planets, and other bodies of our universe are evolved, as also are the different nebulæ which are regarded as similar universes. Concentrating the details upon our own earth, we find that the sequence of events in evolution is quite similar. From the nebulous particles a larger sphere is formed, and gradually, as the result

of tremendous action and interaction, a lithosphere, a hydrosphere, and an atmosphere evolve. The elements undoubtedly originated during this development, and later, when conditions became suitable, the inorganic compounds came into being. These were followed, in logical sequence, by more and more complex combinations, until organic and then living compounds made their appearance. The whole spectacle is a continuous process, starting from a very simple beginning and progressing upward to higher and higher levels.

CHAPTER IV

THE NATURE AND ORIGIN OF LIFE

As soon as animate matter is mentioned, immediately many questions related to it arise. What is life? What are its characteristics? How is it perpetuated from one generation to the next? Particularly, what has been its origin? These queries have been of absorbing interest to man since he first began to investigate nature. The advance of knowledge has tended to clarify some of them, but the main themes of what life actually is, and how it originated, are just as complex at present as they ever have been. The fact is that the progress of science during the last century has opened up many other problems which have made life itself one of the great topics of present-day inquiry.

Living matter is distinguished by the possession of five general characteristics which, in fact, are always present wherever life is found. First, it has the power of organic growth. This means that it grows internally, by putting new parts between the old. Technically, this process is called growth by intussusception, and it is a universal process in all living organisms. In the inanimate world, when growth takes place, it results in an accretion, or an enlargement, on the external surfaces through an addition of new substance. There is no internal augmentation such as occurs in living material.

Second, living matter is characterized by its unique power of undergoing change. Certain of its parts are being broken down, and a simultaneous compensatory action is operating to bring about their repair. In reality, therefore, the processes of waste and repair are going on side by side. This is known as the power of metabolism, embracing both the building-up and tearing-down of tissue. The former process is known as anabolism, the latter as katabolism. In youth these activities go on very efficiently, but the predominant ones are anabolic, or those which make for an increased and decisive growth of the organism. During maturity there is a balance between the constructive and destructive agencies; in other words, the functions involved in metabolism have reached a level of equilibrium, and growth consists merely in the repairing of wasted tissues. In old age katabolism, or tearing-down, becomes ascendant. Waste products are not eliminated as rapidly as they are manufactured, so that small residues accumulate in the tissues and vitally effect the normal reactions of the cells. When the toxic materials have collected in sufficient quantity, they interfere definitely with the vital functions of the organism and, if not removed at the proper time, may lead to death.

A third characteristic of living matter is that it possesses the power of adapting itself to various external and internal conditions. It may be said that the living organism is in a constant state of flux, making the necessary adjustments which enable it to fit efficiently into its surroundings. This characteristic is known as

irritability. Living matter is sensitive and irritable matter, adjusting itself to its environment in as perfect a manner as a piece of plastic material can be made to fit a mould.

The fourth characteristic is that it has the peculiar quality of reproducing itself. During some period in the life of every organism, certain minute entities are set aside which are capable, under the proper conditions, of reproducing all of the structures and functions of the adult parent from which they were derived. This power of reproduction has made possible the immortality of life since its origin upon the earth. In spite of the fact that individual organisms are constantly dying, nevertheless the most indestructible thing in all nature is life. Individually almost all organisms are mortal, but racially they are immortal. This immortality has been made possible by the unique power of reproduction which is possessed by every living thing.

Lastly, one of the most striking traits of living matter is that it possesses a peculiar chemical make-up known as protoplasm. Irrespective of where animate matter exists, whether in the simplest forms or in the highest combinations, this chemical substance is always its underlying basis.

Since the middle of the nineteenth century it has been definitely established that protoplasm is the foundation of all living matter. Scientists have come to realize that, if they are ever to shed more light upon life itself, they must devote a great deal of time and energy to an investigation of this important substance. During the last

seventy-five years many physicists, chemists, and biologists have concentrated their attention on protoplasm, and have made much progress toward an understanding of its physical and chemical properties. Thomas Henry Huxley once defined protoplasm as "the physical basis of life." This was a good definition in his day, when protoplasm was looked upon as a relatively uniform and simple combination, but more recently it has been studied from many angles, with the result that now it has come to be regarded as an exceedingly complex mixture of different compounds.

The disclosures in this field have been so numerous that many scientists have waxed exceedingly enthusiastic over them and at times have made grossly misleading assertions. It is true that we have now a much better comprehension of the physical and chemical properties of protoplasm than we have ever had, but it is likewise true that the actual creation of even the simplest living stuff in the laboratory thus far has never been accomplished. All that one may say, under the circumstances, is that progress along this line has been made, and that some day, perhaps, such a synthesis may become possible under laboratory conditions.

Regarded from a physical standpoint, living protoplasm presents the appearance of a viscid, semi-fluid, and translucent mass. Its true organization becomes apparent when it is studied with the aid of the microscope. Sometimes the predominating structure is that of an interweaving network of fibrils with liquid portions in the open spaces (Figure 11*a*). At other times it is found to have a granular make-up, consisting of

larger and smaller solid particles suspended in a liquid medium (Figure 11*b*), and in other cases it presents the appearance of an emulsion or foam, composed of spherical drops of various sizes resembling compressed

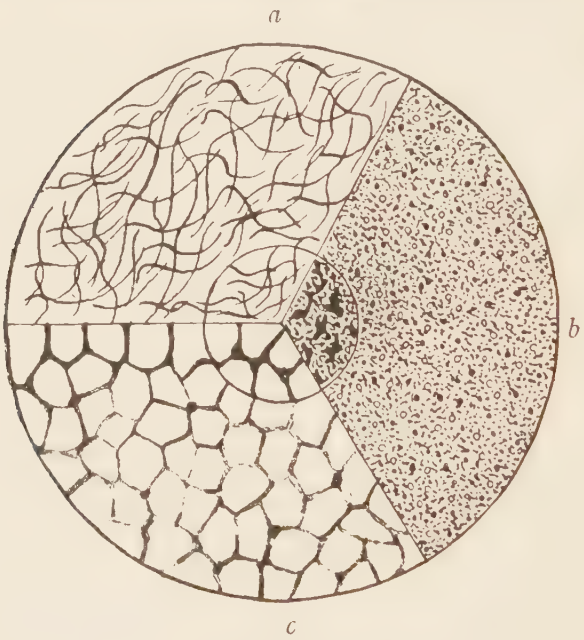


FIG. 11. APPEARANCES OF PROTOPLASM

(From Bailey, Strong, and Elwyn, *Textbook of Histology*. Courtesy of William Wood & Co.)

soap bubbles (Figure 11*c*). This last aspect of protoplasm is the one most commonly encountered. One must not form the impression, from this discussion, that protoplasm is a homogeneously appearing mass, presenting just a single picture. In most instances it is a

composite and heterogeneous mixture, combining in its make-up two or three of the phases which have been mentioned.

Chemically, protoplasm has never been analyzed in the living state, for its animate properties are immediately destroyed as soon as such investigation is attempted. We must bear this fact in mind throughout our discussion. The truth is that whenever any living material is subjected to chemical analysis, invariably something occurs which transforms and fixes it, so that it does not possess the same qualities. That certain something which made it alive has been destroyed. When the biologist is able to analyze living protoplasm in the state in which it is recognized as alive, he may then be able to tell us what life really is; but thus far his attempts in this direction have been futile. All that he has done is to determine what elements enter into the make-up of fixed or dead protoplasm. Meanwhile, inasmuch as no difference can be detected in the weight of the matter after it has lost its living attributes, it is logical to assume that the analysis gives an accurate determination of the essential chemical units which compose it.

Thus far, about twenty elements have been discovered in living matter, and approximately twelve of these are nearly always encountered: namely, carbon (C), hydrogen (H), oxygen (O), nitrogen (N), sulphur (S), phosphorus (P), chlorine (Cl), potassium (K), sodium (Na), magnesium (Mg), calcium (Ca) and iron (Fe). The first four — carbon, hydrogen, oxygen, and nitrogen — are of greatest importance, since they

constitute about ninety-eight per cent of protoplasm, the remaining eight comprising the other two per cent. A most striking coincidence is that these are the elements most commonly found in nature. Furthermore, they show great powers of combination, forming many diverse compounds. We must definitely bear these facts in mind when we discuss the question of the origin of life upon the earth.

In living matter, the elements do not exist as separate entities, but always are united into larger structures known as compounds. Protoplasm really is a mixture of five classes of these compounds: namely, the proteins, carbohydrates, fats, inorganic salts, and water. The first three are classified as organic compounds and are commonly known as foods, whereas the last two are known as inorganic compounds and are believed to afford the medium in which the organic reactions of life take place. The reason for calling the proteins, carbohydrates, and fats organic compounds is that all of them contain the element carbon. Organic chemistry is nothing more than the chemistry of the carbon compounds. Substances which do not contain carbon belong to the inorganic group, and these are relatively more simple in their structure than those of organic nature.

The combinations which have been mentioned are always present wherever life is found, and therefore in recent years biologists and chemists have been investigating them for the express purpose of shedding more light on the problem of the organization of living matter. As a result of these researches, our knowledge

concerning the proteins, carbohydrates, and fats has increased greatly during the last two decades. It is, therefore, of importance that we examine these compounds a little more fully in order to gain a better insight into the *rôles* which they play in living phenomena.

The proteins are, perhaps, of greatest importance. They are composed mainly of the elements carbon, hydrogen, oxygen, and nitrogen; and since they contain nitrogen, they are often spoken of as the nitrogenous organic compounds. Because of their complexity, nobody ever has been able completely to analyze even the most elementary of them. They are huge combinations, the biggest that the chemist has to deal with, and at the same time they are exceedingly intricate. For instance, one of the simplest of the proteins is the reddish pigment hemoglobin, which gives human blood its characteristic red color. The formula showing the composition of hemoglobin, as far as chemists have been able to determine it, is $C_{758}H_{1203}N_{195}FeS_3O_{218}$. It must be emphasized, however, that although this formula does not tell the full story of this relatively simple protein, it does show it to be very complex as compared with such inorganic substances as water (H_2O) or common salt (NaCl).

Aside from the fact that the proteins are the most involved of all of the compounds in protoplasm, they also are found to play the most important *rôle* in living matter. It is believed that they function mainly in the growth and development of the organism. The fundamental animate portions of plants and animals are constructed from them. They are so essential for the

various vital processes that without them no living unit can grow effectively. Moreover, the proteins give tissues their distinctive stamp of individuality, making them specific and different from any corresponding structures of other organisms.

The second class of compounds, the carbohydrates, includes the ordinary sugars and starches, and among these are found many substances familiar to most persons. From a structural standpoint the carbohydrates contain the elements carbon, hydrogen, and oxygen, but there always exists a definite relationship between the hydrogen and oxygen, similar to that which is found in water, — that is to say, there is twice as much hydrogen as oxygen. One of the common carbohydrates is ordinary cane sugar ($C_{12}H_{22}O_{11}$). An examination of this formula discloses that the proportion of hydrogen and oxygen is that which has been indicated.

The carbohydrates afford the fuel and power for living reactions. They combine readily with oxygen, thereby burning quickly and releasing a considerable amount of energy, which the organism can then utilize for the performance of work. In the event that more of them are taken into the body than are needed for the normal activities, the excess is deposited as a reserve supply in certain regions in the form of fatty tissue.

The third class of organic compounds, the fats, contains the same elements that enter the make-up of the carbohydrates — carbon, hydrogen, and oxygen; but the relationship between the hydrogen and oxygen is quite different. In a fat the oxygen content is exceedingly small as compared with the hydrogen content, and

this gives the compound its real value as a producer of heat and energy. One of the common fats, stearin, has the formula of $C_{57}H_{110}O_6$, showing, by comparison, nearly nineteen times as much hydrogen as oxygen. This enormous supply of hydrogen enables the fat to combine readily with large quantities of oxygen within the body, thereby producing a great amount of heat. This undoubtedly accounts for the fact that the fats form such an essential part of the diet of persons residing in the colder climates.

As food, the carbohydrates and fats are utilized exclusively for energy and fuel values; they cannot be converted into definite portions of the living protoplasm, because this unique power is possessed only by the proteins. In a recent treatise on the subject, Professor Parsons of Cambridge University writes as follows:

> Under ordinary circumstance the bulk of the food we eat is used as a fuel. It comes to be burnt up in order to provide the body with the energy of muscular movement and with the heat required to keep it warm. But there is a second and smaller portion of the food which is used for repairing the wear and tear of the tissues of the body. Leaving aside, for a moment, the question of the material required for growth, and considering only the fully-grown organism, we find that fragments of its tissues are being continuously broken down and lost. For protoplasm is a very unstable complex, the continued existence of which depends upon the fact that normally it is built up at one place, so to speak, as fast as it is breaking down at another. The body is thus like any other machine; — not only must it be supplied with

fuel if it is to run, but also it must be supplied with small quantities of material in the form of spare parts for the replacement of such components of its mechanism as become damaged or worn out during use. These two uses are subserved by the material taken into the body as food. Under ordinary circumstances most of this is used for fuel, but a certain proportion is required for the very important function of repairing the wear and tear of the tissues.

Now it is easy to see that in these processes proteins play a unique part. For, since the tissues of the body consist so largely of proteins, it is obvious that it is only the protein part of the food which can supply that material which is required for the replacement of the wear and tear, whereas all classes of foodstuffs, including fats and carbohydrates as well as proteins, can be used as fuel. Fats and carbohydrates cannot build up the tissues simply because these foodstuffs contain no nitrogen.[1]

The inorganic compounds, consisting of water and various salts of sodium, potassium, calcium, and the like, do not play any part in either food or fuel values, but their *rôle*, as has been mentioned already, is simply to act as solvents and regulators, so that the organic reactions may take place efficiently and effectively. However, it must be remembered that they are very important in the activities of living matter, inasmuch as they afford the medium in which the transformations occur. Anything which disturbs the normal content of this medium may, at the same time, seriously affect the vital activities going on within the organism.

[1] *Fundamentals of Bio-Chemistry,* Baltimore, Williams and Wilkins, 1925, pp. 42–43.

During the last century scientists have discovered the means of manufacturing a great many of the compounds which make up protoplasm. The inorganic substances are, of course, easily produced in the laboratory, but in the case of the organic compounds chemists have found that, although it is possible to construct a large number of carbohydrates and fats, the proteins do not lend themselves to such synthesis. In this connection it must be pointed out that the German chemist, Emil Fischer, and his students have succeeded in building up, in the laboratory, huge combinations that closely resemble the proteins. Starting with simple amino acids, which are the ultimate products of the breaking-down of proteins, they have gradually produced more and more complex substances, such as the polypeptids, which approach closely the proteins themselves. Prior to 1828 it was deemed impossible that any organic compound could be developed outside of the living organism, but in that year Wöhler manufactured the organic compound urea in his laboratory, and since then hundreds of similar compounds have been synthesized under laboratory conditions.

The compounds that comprise living matter may assume two phases, known technically as colloidal and crystalloidal. In reality, the protoplasm of the living organism consists essentially of a mixture of crystalloids and colloids, either dissolved or suspended in a watery medium. When a substance exists in one of these states it has entirely different properties, and a number of definite features distinguish each form.

One of the first properties of a crystalloid is that it has a distinct shape as indicated by its crystalline form. The crystals, of course, vary with the particular substance, but they are so definite that chemists can easily recognize any crystalloidal compound simply by examining the patterns of the respective crystals. On the other hand, colloids are amorphous, that is, without any specific shape or form. The particles are irregular in appearance and may exist in larger or smaller masses, depending on the circumstances.

A second quality which characterizes these two phases of matter is that crystalloids form true solutions, whereas colloids produce only suspensions. When crystalloids are poured into water they soon disappear and merge with the fluid medium, so that the whole mixture becomes a homogeneous mass. Under no circumstances can the crystalline particles be recognized, for a true solution has taken place. On the other hand, when the powdered particles of a colloid are placed in water they do not dissolve but tend to suspend themselves. At first no difference can be detected in the color of the liquid, but the mixture gradually becomes cloudy, more turbid, and thicker in consistency, as more and more of the colloid is poured into it. Investigation with the microscope reveals that particles have not gone into solution; they have suspended themselves as minute solids in the fluid.

A third distinguishing feature is that a crystalloid is always found to possess a saturation point. This means that the liquid which acts as the solvent will dissolve just so much, and no more, of the crystalloidal sub-

stance. When more of the crystals are added after this saturation point has been reached, they will not dissolve but will merely sink to the bottom of the solution and appear as a solid mass. In the case of a colloid, since no solution is formed, no saturation point is reached; as more of the colloid is poured into the liquid the mixture becomes thicker and thicker, until finally it assumes a glue-like appearance.

The fourth feature which differentiates these two phases of matter is their relative complexity. The crystalloids are quite simple and the chemist expresses this by saying that they are compounds of low molecular weight. On the other hand, the colloids are huge combinations of such tremendous molecular weights that they are considered the most complex substances known in chemistry.

A fifth characteristic is that crystalloids can diffuse or pass through animal membranes, whereas colloids do not possess this faculty. From a physical standpoint this power of diffusion through animal membranes is known as osmosis. The measure of the rate of diffusion of any substance is expressed as the osmotic pressure exerted on the particular membrane by a substance which passes through it. Since crystalloids have the ability to pass through animal membranes, they exert a definite osmotic pressure which can readily be measured. On the other hand, since the colloids do not diffuse, they remain within the cells of organisms and therefore exert no osmotic pressure.

These are the chief characteristics which distinguish substances in the colloidal and crystalloidal states.

They may be briefly summarized in tabular form as follows:

Properties of Crystalloids	*Properties of Colloids*
1. Are crystalline substances.	1. Are amorphous substances.
2. Form saturated solutions and readily crystallize out from solution.	2. Do not form saturated solutions and do not crystallize from solution.
3. Reach a point of saturation resulting in the formation of a saturated solution.	3. Reach no point of saturation but the suspension becomes thicker and thicker, finally forming a viscid gum.
4. Are simple chemical compounds possessing a low molecular weight.	4. Are complex chemical compounds having a high molecular weight.
5. Diffuse readily through animal membranes and possess an osmotic pressure.	5. Do not diffuse through animal membranes and possess no osmotic pressure.

Good examples of crystalloids are table sugar, table salt, fatty acids, glycerine, urea, and amino acids. Substances such as gum, glue, gelatine, and egg albumen are typical colloids.

When the colloids first were investigated by Thomas Graham, the English physicist, in 1861, he looked upon them as entirely distinct from the crystalloids. To Graham, colloids and crystalloids represented two separate spheres of matter with no transitions between them, but later research proved that these were arbitrary distinctions. While it is quite true that a colloid has properties entirely different from those of a crystalloid, yet it must be recognized that both are transitory states of matter. Many, if not all, compounds may assume the colloidal condition at one moment and the crystalloidal at the next, and vice versa. This power of

change, back and forth, from the colloidal to the crystalloidal state seems to be the very essence of life. For instance, the colloidal proteins within tissues are ordinarily broken down, step by step, into simpler substances until they become crystalloidal amino acids, which can then be removed or eliminated by osmosis from the various cells which comprise the tissues. Similarly the colloidal carbohydrates gradually disintegrate into crystalloidal sugars, while the colloidal fats break down to form crystalloidal soaps and glycerine. All of this goes on during the normal life within the cells of the body of an organism. In like manner the simple crystalloidal substances within the cell are built up to form the complex colloidal compounds. These changes are occurring constantly in all living protoplasm, and they account for the numerous complex reactions which take place within it. It is therefore important to recognize that, in order to comprehend life, we must first understand the reactions and interactions of the three substances which enter into living combinations; namely, water, crystalloids, and colloids.

After this preparatory discussion, we are ready to consider the subject of how living matter, with its unique characteristics and its underlying basis of protoplasm, first came into existence. So far as anyone now knows, life and living matter arise only through the giving-off of minute living particles from living organisms; but in the history of this universe there must have been a time when the first living matter made its appearance. This question, of course, is not a new one; it

is as old as human thought. Man became interested in it when he reached the level of a thinking being, and since then he has been trying to find a satisfactory answer to it. In general, four main theories have been developed to account for the first creation of life on earth.

Perhaps the oldest conception is that of *special creation,* which we have already discussed to some extent in the chapter dealing with the origin of matter itself. We must emphatically assert that scientists as a whole do not accept this view of creation, because it is contrary to all known facts. One of the most firmly established principles in all science is embodied in the law of change — that transformations have been taking place in this universe, particularly on the earth, for many millions of years. Geologists and paleontologists have shown conclusively that transitions have occurred and that different types of organisms have populated this earth in bygone ages.

The second hypothesis is that of *cosmic-panspermia,* which originated in the nineteenth century. The theory was propounded in 1865 by Richter, a German scientist, and it immediately received the indorsement of Helmholtz, one of the great scientific leaders of the time. According to this view, life is as old as inorganic matter itself, but it originated on some cosmic body of the universe other than the earth. It is assumed that in those places where life happened to be, minute living particles, in the form of cosmic dust, were constantly being given off to the external surroundings; and when some of them happened to drift to other celestial bodies,

where conditions were favorable for life, they then developed into living forms.

There are numerous objections to this conception. Even the Swedish physicist Arrhenius, who accepted this view, estimated that if living germs were carried through the ether, by luminous or other radiations, it would take them about nine thousand years to be transported from the nearest stellar system to the earth; and from Mars, which is the planet nearest to the earth, it would take about twenty days. It is inconceivable that these minute living particles could withstand such a long and strenuous journey.

In 1871, Lord Kelvin of England propounded a somewhat different version of the cosmic-panspermia conception, namely, the so-called *meteorite theory,* in which he argued that life was brought to our earth on meteorites from other planets or stellar systems. A meteorite is a huge metallic mass which is broken off and flung out into space when two celestial bodies of large magnitude collide. Many meteorites are constantly moving about and occasionally one of them finds its way to the earth. Lord Kelvin assumed that if one of these masses which happened to fall upon the earth came from a cosmic body upon which life existed, it might easily bring living germs with it; and these could then afford the means for the origin of organisms upon our own planet.

To Kelvin's point of view, however, there are also serious objections. It has been estimated that it would take a meteorite about sixty million years to travel from the nearest stellar system to the earth, and from the

nearest planet, Mars, approximately one hundred and fifty years. Furthermore, the heat engendered by the meteorite during its passage to the earth, as well as its terrific impact when it reached our planet, would be so great as completely to destroy all life that might be carried by it. The cosmic-panspermia theory, no matter in what form it has been expressed, does not solve the question, for it does not tell how life originated; in other words, it evades the problem, and most scientists have rejected it completely. This does not mean that life may not exist on some of the other heavenly bodies; but it must be remembered that we are chiefly interested in finding out the forces, agencies, and other factors which have been responsible for the origin of living matter upon our own planet, the earth.

The third conception is that of *spontaneous generation,* which states that living organisms have arisen in perfect forms, and are always originating, from the non-living environment of the earth. As becomes self-evident from an examination of the facts, this theory postulates that there is an intimate relationship between living and non-living matter, and that under the right conditions the former is produced from the latter. Although this theory has now been abandoned, it has played a very important *rôle* in the history of science. It held sway from the time of Aristotle, who lived between the third and fourth centuries B.C., to the latter part of the nineteenth century. So devoutly was it accepted that many scientists elaborated formulæ for producing such complete organisms as maggots, worms, insects, fishes, frogs, and even such highly developed

forms as mice. Moore[2] tells us that Van Helmont, a famous physicist and chemist of the sixteenth century, gave the following prescription for generating mice:

> Place dirty linen in a receptacle together with a few grains of wheat, or a piece of cheese, and shortly mice will make their appearance.

This same author gave the following naïve recipe for producing scorpions:

> Scoop a hole in a brick and put some crushed sweet basil into it. Lay a second brick on the first so as to completely cover it. Expose the two bricks to the sun and at the end of a few days the smell of the sweet basil acting as a ferment will change the herb into real scorpions.

A short time ago an old volume on natural history, published in 1658 by an English physician and divine, Dr. Edward Topsell, came to the attention of the author. It is entitled *The History of Four-footed Beasts,* and in it is found this unique statement concerning the belief in the idea of spontaneous generation:

> We have shown already, that all kinds of Mice are generated out of the earth, although also they suffer copulation. And in Egypt it is very common about Thebes, and the places where the Nile overfloweth, that in the decrease and falling away of the Waters, the sun engendereth many Mice upon the slime of the earth; so that it is ordinary to see at one time their foreparts to have life, flesh, and motion, and the hinder-parts deformed, and nothing but earth.

During the seventeenth century the first critical investigation to disprove the theory of spontaneous

[2] *The Origin and Nature of Life,* New York, Holt, 1912, p. 164.

generation was started. An Italian physician, Francesco Redi, in 1668, was the first to question the idea. In his experiments he covered meat with fine gauze and wire netting, which prevented insects from coming in contact with it, and he showed that under these circumstances no maggots developed. At about the same time a Dutch physician by the name of Swammerdam performed similar experiments and arrived at the same conclusions. Scientists, however, were slow to accept these findings. Furthermore, in the seventeenth century the microscope was invented, and this wonderful instrument, instead of disproving spontaneous generation, tended to establish it more firmly than ever before. Scientists pointed out that when ordinary pond water, which was at first clear and showed no life within it, was allowed to stand exposed to the air for some time, it became cloudy; and when examined with the microscope it was found to swarm with innumerable living forms.

Basing their arguments on such evidence, the scientists of the time held that in some mysterious fashion the organisms which developed in the mixture were produced through a change in the simple chemical substances originally contained therein. This conclusion led to some famous experiments in the eighteenth century, particularly by the English priest Needham, who upheld spontaneous generation, and the Italian priest Spallanzani, who opposed it. The Italian priest showed that when sterile cultures were used in glass flasks which were hermetically sealed, no organisms developed within them. He also proved that when some of these sealed flasks were tapped hard enough to pro-

duce a slight crack, then organisms always developed within the culture medium, showing quite conclusively that the inrushing air contaminated the mixtures by bringing in spores and germs.

The climax in the controversy on spontaneous generation was reached in 1859, when the French naturalist Pouchet published a voluminous book entitled *Heterogéné,* in which he argued vigorously for spontaneous generation and completely summarized the various methods for engendering living organisms. This led directly to the famous work of the French genius, Pasteur (Figure 12), and the English physicist, Tyndall. Pasteur by a series of brilliant investigations, in which he repeated Pouchet's experiments, showed that the organisms which developed within sterile infusions exposed to the atmosphere were the direct result of contamination by dry spores or germs that were floating in the air. He showed further that if care were taken to screen out the floating spores or germs, so that the air which finally came in contact with the infusions was perfectly sterile, then no living organisms of any kind appeared. He established this contention in a convincing manner when he opened some twenty flasks containing boiled infusions on top of the Mer de Glace in the Alps mountains, where the atmosphere was thoroughly clean and without any dust particles suspended in it.

Pasteur's most conclusive experiment was performed in 1861, when he devised a peculiar glass flask which was completely closed except for an opening in one of its sides, to which was fused a long glass tube that had

been bent in two places, so that it first went down, then up, and finally down again (Figure 13). Prior to the attachment of the tube the flask was half filled with water contaminated by a large number of microscopic

Fig. 12. Louis Pasteur

organisms. By boiling at intermittent intervals, all of the living forms were completely destroyed, and the entire contents of the flask were rendered sterile. At the same time the escaping steam tended to condense and accumulate in the lowest portion of the bent tube, so

that a complete water barrier was formed there. After the flask had cooled sufficiently to allow the outside air to penetrate its interior, it was noticed that the water which had collected in the tube acted as an effective screen, capturing all the dirt and germ particles, so that the air which finally reached the sterile mixture at the

FIG. 13. PASTEUR'S FLASK

As used in his spontaneous generation experiments. Note the bend in the tube. (From McFarland, *Biology, General and Medical.* Courtesy of W. B. Saunders Co.)

bottom of the flask was thoroughly pure and clean. The result was most striking, for within the flask proper no life developed, whereas in the water barrier in the bent tube a host of minute, free-living organisms soon came into existence.

Tyndall corroborated the contentions of Pasteur by showing that infusions, made sterile by boiling, and

placed in an air-tight box which was allowed to stand exposed for several weeks, did not reveal the slightest signs of life. Pasteur and Tyndall dealt the idea of spontaneous generation its final blow, and since then scientists almost unanimously have abandoned the conception. However, one must not forget that, even though this is the situation, J. Arthur Thomson's contention remains true:

> The conclusion then, which most modern biologists accept is, that while there is no known evidence of not-living matter giving origin to living organisms, this does not necessarily exclude (a) the possibility that this once took place, (b) the possibility that it is taking place now, or (c) the possibility that it may be made to take place again.[3]

The fourth and last conception regarding the origin of living matter is the *physico-chemical evolution theory,* which states that living matter slowly evolved from the simple non-living materials of the earth when conditions upon our planet became suitable for the occurrence of such a phenomenon. At first the living substance was exceedingly elementary, probably much more so than any with which we are now familiar, but gradually, as the environment evolved into a more complex state, the living material adapted itself and similarly became transformed.

This view assumes the spontaneous generation of the first living matter upon the earth, but it differs considerably from the crude idea of spontaneous generation which has been discussed. The physico-chemical evolu-

[3] *The Science of Life,* London, Blackie & Son, 1899.

tion theory states that the first, simple living stuff originated spontaneously, probably many millions of years ago, when forces and conditions made such an occurrence possible. As soon as life made its appearance, it evolved, through adaptation resulting from the action between itself and the environment, into higher and more complex forms.

In considering geologic evolution we pointed out that as the earth developed into a larger and more complex sphere, the lithosphere consisting of the various rock formations, the hydrosphere embracing the waters, and the atmosphere containing the gases, took on definite shape. To bring about these transformations tremendous stores of energy must have been present within the earth itself. Many scientists, visualizing the origin of living matter, are of the opinion that during these early periods, when there was tremendous heat and energy on the earth, the various elements such as carbon, hydrogen, oxygen, and nitrogen combined into a sort of primitive compound which possessed some of the properties of living matter. Slowly, but definitely, more and more intricate combinations emerged until a simple living substance was formed, and this gradually evolved to higher levels of complexity, ultimately culminating in all of the diversified types of plants and animals.

Pflüger [4] was one of the first to draw a concrete picture of how this process took place. In 1875 he propounded the idea that life had its inception around the combination of cyanogen (CN) at the time when the

[4] "Ueber die physiologische Verbrennung in den lebendigen Organismen," *Arch. f. d. ges. Physiol.*, vol. 10 (1875).

earth was an intensely hot mass. Because living matter shows mainly a protein nature, Pflüger asserted that the first type of living entity was probably a mixture which was similar to the living proteins found in the organisms of the present day, although, relatively, it was simpler. The emergence of such a combination probably occurred when the earth had cooled sufficiently to permit precipitation and the formation of the hydrosphere, for within the waters, besides hydrogen and oxygen, large quantities of different salts and gases must have existed in a dissolved state. It should not be forgotten that the earth was still intensely hot, and that tremendous action and interaction were taking place constantly. Pflüger is of the opinion that under such conditions the cyanogen mixture combined with the various substances inherent in the waters to form a number of exceedingly simple protein compounds, some of which eventually united to produce living protoplasm.

Moore, on the other hand, believes that living matter appeared when the earth had cooled sufficiently to allow the complex living combinations of protoplasm to make their appearance. In 1912 he asserted "that as soon as temperature allowed sufficient complexity of chemical structure for life to be borne upon the earth, then life appeared." [5] Moore's contention is that, as soon as conditions upon the earth permitted it, simple inorganic substances, such as the oxides and carbonates, were evolved, followed by inorganic colloids similar to those of alumina and silica which may now be seen deposited in many sedimentary formations, by the organic col-

[5] Moore, *op. cit.*, pp. 186–187.

loids, and finally by simple living matter. He summarizes the whole cycle

> as a general law universal in its application to all matter, although varying in intensity in different types of matter, and holding throughout all space as generally as the law of gravitation — a law which might be called the *Law of Complexity* — that matter, so far as its energy environment will permit, tends to assume more and more complex forms in labile equilibrium. Atoms, molecules, colloids, and living organisms arise as the result of the operations of this law, and in the higher regions of complexity it induces organic evolution and all of the many thousands of living forms.[6]

Dr. Schäfer,[7] in his presidential address delivered in 1912 before the British Association for the Advancement of Science, vividly pictures the evolution of life. At first, he says, a simple colloidal slime made its appearance as the result of the aggregation of the simple non-living structures of the earth. After a long time this colloidal slime became organized into a form of protoplasm possessing qualities similar to those of the nucleus of a modern cell. Finally the nucleated cell was established and hosts of cellular organisms came into being. From them, by degrees, have evolved all of the varieties of aggregate life consisting of the various known types of many-celled organisms which have ever existed, or which now exist, upon the earth.

In 1916 Professor Osborn[8] put forth a view

[6] *Idem,* pp. 188–189.

[7] "Life: Its Nature, Origin and Maintenance," from the *Smithsonian Report for 1912,* pp. 493–525.

[8] *Origin and Evolution of Life,* New York, Scribner, 1917.

concerning the origin of life, in which he incorporated five hypothetical steps. First, there was an assembling of the various chemical elements which now are found to be essential to life, from the water, air, or land formations of the earth. Second, these life elements united into a new bond of organic unity, an *individual* or *organism* which was distinctly different from any of the other combinations of inorganic matter previously produced through the action of the forces of gravity. Third, this new grouping occurred in the form of a colloidal suspension similar to that found in all living cells. Fourth, as this life material became specialized and gave origin to diversified plant and animal functions, there also arose various "chemical messengers" or "catalyzers" (enzymes, internal secretions, and the like) which could regulate or control the living reactions. Fifth and last, all of the various life forms were soon subjected to the action of the agencies of competition and natural selection, resulting in the origin of newer and better types.

Dr. Charles B. Lipman, in an interesting article, expresses the situation as follows:

> Thus, we can imagine that in the early history of the terraqueous mass which was then the earth, with high temperatures and great chemical electrical activity existent, such substances as carbon dioxide, water and nitrates may have been caused to combine in such fashion as to produce a pattern of molecule in which the behavior of the substance in regard to motion, growth and reaction with its environment was not, perhaps, the same, but in a primitive way, similar to that of an amœba, and we would have our first living molecule. This molecule would then, under certain

conditions, react with other molecules and gradually build up more and more complex chemical aggregates until perhaps after geologic ages, the proteins and protoplasm itself would be evolved.[9]

Although no one, under laboratory conditions, has succeeded in manufacturing living matter out of the non-living materials of the environment, yet in nature the green plants are constantly doing this very thing. For the benefit of persons who are not familiar with plant physiology, it may be stated that in every green plant there is an efficient agent, chlorophyll, capable of extracting energy from sunlight and utilizing it to initiate transformations in such simple substances as water, inorganic salts, and carbon dioxide, which enter the plant through the root system or leaves, and lead to the formation of such complex organic compounds as the carbohydrates, fats, and proteins. Ultimately portions of these compounds are converted into the essential parts of the living matter of the plant itself. The initial process in this entire cycle is known as photosynthesis, and it is quite efficient in starting the reactions which finally lead to the construction of living matter.

An analysis of the complete cycle reveals the fact that three things are essential for its proper operation: first, simple chemical combinations such as carbon dioxide, water, and inorganic salts; second, energy, such as that contained in sunlight, for performing the chemical transformations; and third, a suitable compound, similar to chlorophyll, which can act as an

[9] "Origin of Life," *Scientific Monthly*, vol. 19 (1924), pp. 357–367.

efficient machine for the purpose of utilizing the available energy to bring about the necessary changes in the simple stuffs of the environment, so that they may be combined into higher and more complex substances, and eventually culminate in the formation of living material. Since this is the logical procedure in nature, is it not reasonable to assume that before any living substance could come into existence upon the earth, some similar three steps were necessary? Most investigators are of the opinion that the conditions, while not, perhaps, nearly as complex as they are at present, were undoubtedly much the same.

As has been pointed out, the inorganic substances, particularly those found in living matter, undoubtedly existed in great abundance when the earth assumed definite shape. Likewise, a great deal of energy was present from two sources — the sun, and the interior of the earth itself. What we are in doubt about is the agent which was first developed that could act as a machine for utilizing this energy for purposes of building living matter out of the available materials. If we can find a satisfactory answer to this question, then we can easily imagine how the first living matter arose. Scientists have no definite knowledge about it at the present time, but judging from what they do know of what goes on in all green plants they are convinced that this primitive compound or machine must have been somewhat similar to green chlorophyll, although probably less complex in its make-up.

In recent years chlorophyll has been chemically analyzed, and has been found to be a colloidal com-

pound consisting of the elements carbon, hydrogen, nitrogen, oxygen, phosphorous, and magnesium. It is entirely conceivable that under the right conditions certain of these elements were aggregated into a primitive substance having qualities somewhat like those of chlorophyll. Although this substance was much simpler than the chlorophyll found in existence today, nevertheless it must have been quite efficient in initiating the first reactions that led to the production of the primitive living organization.

According to the physico-chemical evolution view, then, evolution is a continuous process. When energy conditions became favorable, atoms, then molecules, inorganic compounds, organic compounds, colloids, and ultimately living organisms appeared. The first forms, in all likelihood, were exceedingly simple, much more so than any of the types existing today. Also, they were extremely unstable, undergoing changes very readily. Probably none of them has survived to the present time, although some investigators believe that they are being formed today just as they were in bygone ages. The English scientist Allen[10] believed this to be the case, and asserted that the only reason why these primitive living combinations could not be found was because they were devoured by the already existing organisms just as soon as they were produced. Moore expresses a similar opinion when he asserts that

> there must exist a whole world of living creatures which the microscope has never shown us leading up to the bacteria

[10] "What is Life?" *Proc. Birmingham Nat. Hist. and Philos. Soc.*, vol. 11 (1899), pp. 44–67.

and the protozoa. The brink of life lies not at the production of protozoa and bacteria, which are highly developed inhabitants of our world, but away down amongst the colloids, and the beginning of life was not a fortuitous event occurring millions of years ago and never again repeated, but one which in its primordial stages keeps on repeating itself all the time and in our generation. So that, if all intelligent creatures were by some holocaust destroyed, up out of the depths in process of millions of years intelligent beings would once more emerge.[11]

It has been an interesting question whether the first organisms were plants or animals, or types of a distinctly different character, and here, once more, a positive assertion becomes impossible. Most students believe that these primitive forms possessed many of the combined features of the plant and animal world, so that they were really organisms of a plant-animal nature. Numerous similar types are in existence today, such as Euglena and Volvox, which show the traits of both. The botanist often claims them as representatives of plants, whereas the zoölogist no less often classifies them as animals. Strictly speaking, they must be regarded as plant-animals. Undoubtedly the primordial living combinations were very much simpler than any of the plant-animals of the present time, and from them, through adaptation and specialization, the distinctive plant and animal kingdoms have evolved.

[11] *Op. cit.*, pp. 190–191.

CHAPTER V

THE TREE OF ANIMAL EVOLUTION

The first life which appeared on the earth was exceedingly primitive and simple as compared with present life. Many scientists now believe that the first living matter was in many respects similar to the lowest of the bacteria, those commonly classified as the primitive feeding forms. These organisms are so simple that they are capable of deriving energy and food from the primary inorganic materials of the environment. Apparently they do not need sunlight to maintain their vital processes; furthermore, they seem to exist without any of the complex organic compounds which are so essential to the more specialized plants and animals.

It undoubtedly required a great length of time for this elementary life to make its appearance, but once it became stabilized, it adapted itself to the transforming conditions of the environment until better and more nearly perfect combinations developed and gradually supplanted it. After many millions of years of such adjustment, more enduring forms emerged, and these paved the way for the formation of the present-day organisms. Plants and animals as we know them were thus established, and a close examination of them shows a definite transition from the simplest to the most

complex types. This evolution may be illustrated by representatives of the animal kingdom.

In spite of the fact that a great wealth and diversity of animals exist upon the earth, these show so many points of similarity that they can be organized into a few definite groups, differing in their degree of complexity, yet so linked together by innumerable ties as to indicate clearly an identity of origin. Because of this close resemblance between the groups, the animal world may be compared, figuratively, with a growing tree, having a main trunk and a number of large branches, each one of which, although more or less independent, is nevertheless distinctly joined to the others, the entire structure forming a unified and unbreakable whole (Figure 14). Occasionally some of the limbs appear indefinite, while others seem impaired or even lost; but as the life of the earth becomes better understood, the parts of the broken or missing branches are often discovered, and invariably they help to strengthen the conception of a continuous progression.

Undoubtedly this tree of the animal kingdom had its roots in the first primitive undifferentiated living material, and, as time went on, it branched into diversified units. The main trunk must be regarded as the direct line of emergence of complexity, representing the more generalized animal forms, and from this the more specialized groups have arisen. Few of the generalized types have persisted to the present day, for as the trunk grew they were gradually absorbed or effaced, so that most of them long ago passed out of existence as distinct entities and may now be recognized, in some instances,

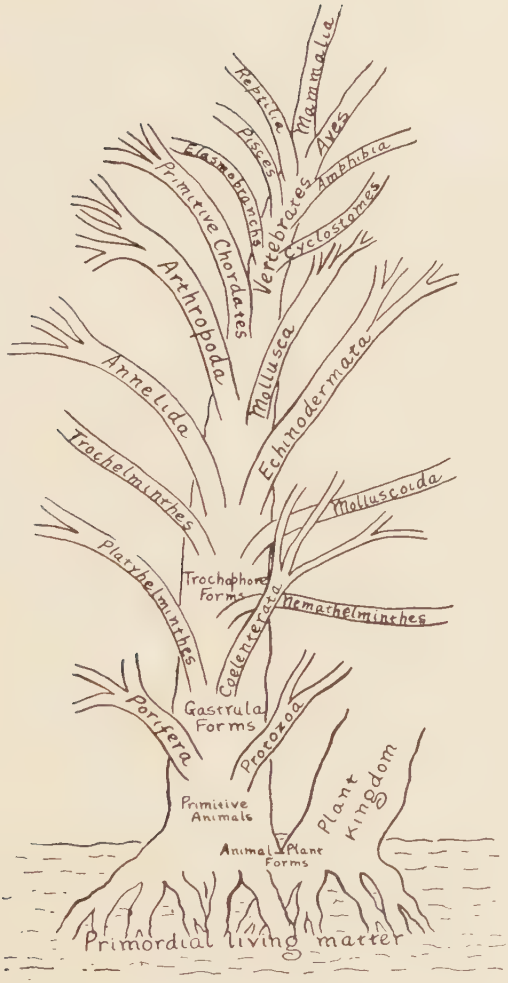


FIG. 14. THE TREE OF ANIMAL EVOLUTION

as transitory stages during the early development of the more particularized organisms.

The various groups are represented today by the main categories of the animal kingdom, known as phyla, and these are indicated on the tree as distinct side-branches that take their origin directly from the trunk. These major limbs have themselves evolved, producing smaller twigs, indicating the lesser divisions of the animal world, such as classes, orders, families, genera, and species. In cases where the main branch is broken or missing, these smaller units seemingly are isolated and distinctly set apart from the rest of the animal kingdom; but, at intervals, forms are discovered, so-called "missing links," which tend to bind these separate entities to the main trunk in such a manner as to strengthen the evolutionary point of view. In order intelligently to discuss the evidence for evolution, one must clearly understand the sequence of the various phyla of animals. An exhaustive treatment will not be attempted here, inasmuch as any good textbook of zoölogy gives such information. The object of the present discussion is merely to point out the principal characteristics of each phylum, and particularly to mention the points of resemblance between it and the other groups, in order to indicate the logical advancement within the animal kingdom.

1. The Invertebrate Phyla

The first eleven phyla of the animal kingdom, embracing all species from the Protozoa to the Arthropoda

inclusive, are known collectively as invertebrates. The one main characteristic by which they may be identified is the complete absence of any internal bony skeleton. Each phylum has its distinguishing attributes which separate it definitely from the other invertebrates.

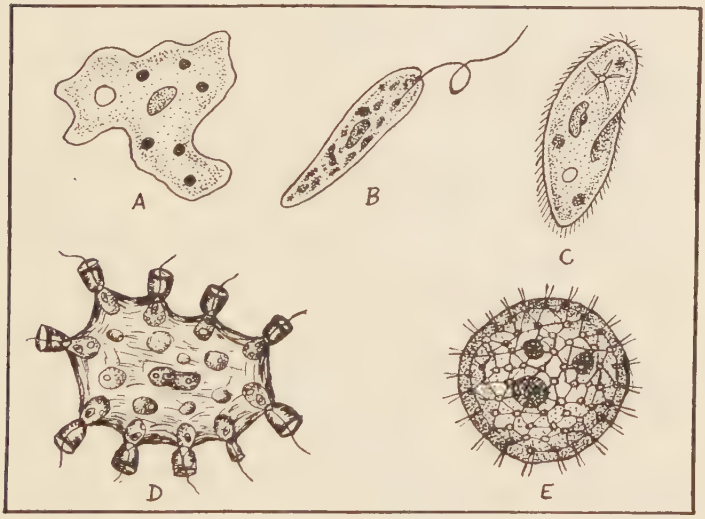


FIG. 15. PROTOZOA

A, amoeba; B, euglena; C, paramoecium; D, choanoflagellata; E, volvox.

Phylum 1. Protozoa. — The Protozoa (Figure 15) are the most elementary animals, consisting either of single cells or of a group of similar cells organized into a loose colony. The phylum contains approximately eighty-five hundred species, most of them single-celled forms with little or no differentiation, but performing all of the functions common to the most complex of

animals. In the colonial types the first indication of an association of cells appears, and these colonial Protozoa possess some degree of division of labor into purely bodily and purely reproductive functions. The Protozoa are significant because all higher animals begin their development as single cells which, through a process of cell multiplication, soon become organized

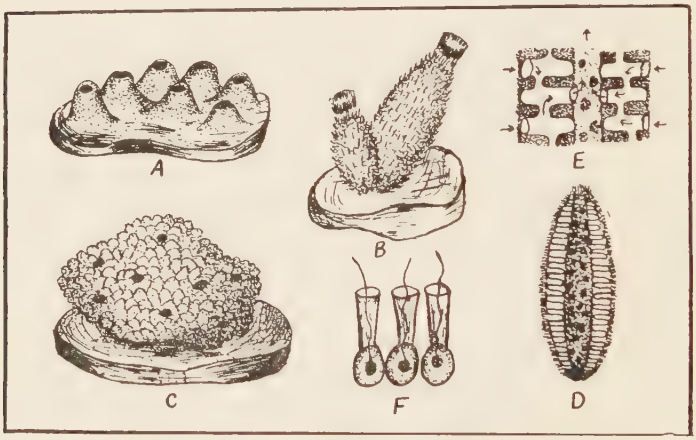


FIG. 16. PORIFERA

A, volcanic sponge; B, grantia, a simple sponge; C, bath sponge; D, longitudinal section through grantia; E, path of water through canals; F, choanocytes, or collar cells.

into many-celled structures, comparable, in various respects, with the colonial Protozoa.

Phylum 2. Porifera. — This phylum consists of the sponges (Figure 16) and is considered the least complex of the many-celled animals, the so-called Metazoa. The cells are organized definitely into different layers known as tissues. The Porifera are the simplest of

the tissue animals, and include approximately twenty-five hundred species. All of them are characterized by possessing some kind of skeletal framework of either lime or silicon, or a silk-like substance known as spongin, and around this the living material of the sponge itself is organized. No organ systems of any kind have developed as yet. There are numerous surface pores on the body and these connect with canals that come from the interior. Along some of these canals are peculiar cells with long flagella commonly called "collar cells" and technically known as choanocytes (Figure 16, F). The choanocytes engulf food and, at the same time, the beating of the flagella creates within the canals water currents which carry oxygen and nutritive material to various parts of the body, and which remove the waste products as well. It is significant to note that there are only two places in the animal kingdom where cells of this type are found: the colonial Protozoa, belonging to the group known as Choanoflagellata (Figure 15, D); and the Porifera. Basing their views on evidence of this sort and also on the fact that no organ systems have as yet been established, most zoölogists believe that the Porifera developed from a protozoan ancestor similar to one of the colonial Choanoflagellata. In this connection it is interesting to know that the older zoölogists regarded the Porifera as offshoots of the Protozoa, little higher than the colonial forms which are found at the present time.

Phylum 3. Coelenterata. — About fifty-two hundred species comprise this phylum, including many

well-known representative types such as the jellyfishes, marine hydroids, coral-producing forms, and sea anemones (Figure 17). All are water-dwelling animals in which specialization has progressed to the ex-

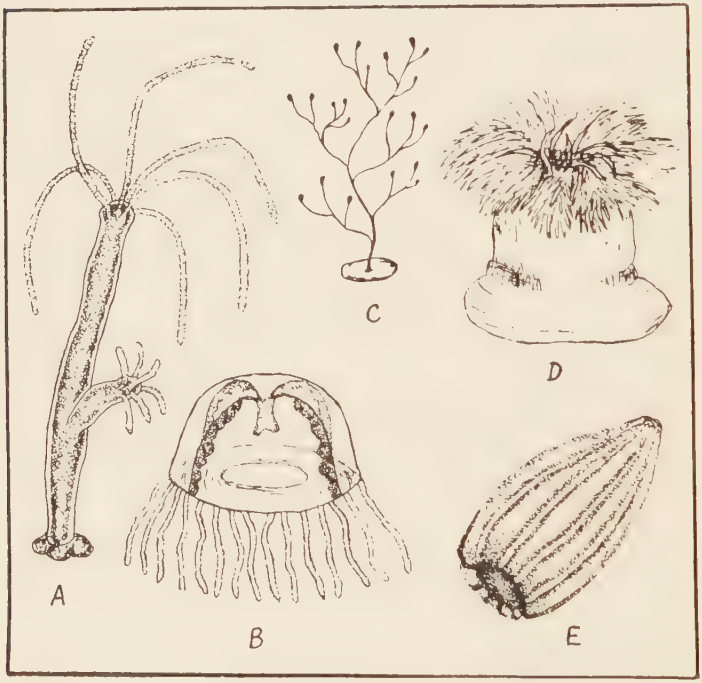


FIG. 17. COELENTERATA

A, hydra; B, jellyfish; C, marine hydroid; D, sea anemone; E, ctenophore, or comb-jelly.

tent of producing a definite beginning of organ systems. The body of the Coelenterata consists of two distinct layers, a condition termed diploblastic, the outer one known as the ectoderm, and the inner one as

the endoderm. These layers are arranged so that the body assumes the appearance of what is known in zoölogy as a typical gastrula (Figure 44). It is rather significant that all of the higher Metazoa show some form of gastrula in their embryonic development. This phenomenon is so universal in its occurrence that biologists have postulated a theory which agrees well with the one propounded first in 1874 by Ernst Haeckel, namely, the *gastraea theory,* which states that some gastrula-like ancestor existed in the past, from which have evolved all of the Metazoa that pass through this typical stage in their development.

The Coelenterata show radial symmetry, and the digestive system consists of a sac-like cavity with one opening acting both as the mouth, the place for the intake of food, and as the anus, the place for the expulsion of undigested solid wastes. The most highly developed Coelenterata, the class known as Ctenophora and commonly called the "comb-jellies," are forms showing a tendency to bilateral symmetry, some of them being elongated and worm-like in appearance. Many zoölogists classify the Ctenophora in a distinct phylum a little higher in the scale of evolution than the other coelenterates.

Phylum 4. Platyhelminthes. — The Platyhelminthes (Figure 18), more generally known as flatworms, either dwell freely in water or may exist as parasites in various hosts. In the flatworms there is a more definite establishment of organ systems than in any of the phyla thus far considered, although the digestive system, when present, has not advanced beyond the sac-like type.

Moreover, the beginning of a third layer of cells, called the mesoderm, has appeared. In contrast with the Metazoa, already discussed, the Platyhelminthes are the first three-layered, or triploblastic, animals encountered; their bodies consist of an outer ectoderm, an inner endoderm, and a slightly developed mesoderm situated between the other two layers. Beginning with this phylum, all of the animals included in it, as well

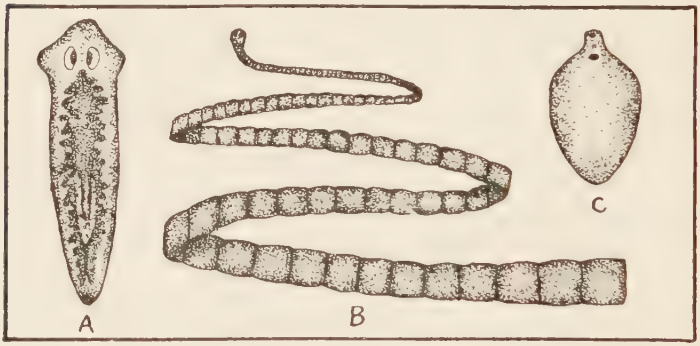


FIG. 18. PLATYHELMINTHES

A, planaria; B, tapeworm; C, liver fluke.

as those above it, are triploblastic, possessing three well-defined tissue layers.

The Platyhelminthes comprise about five thousand species. The most commonly accepted belief is that they originated from an ancestor similar to the comb-jelly. As will be recalled, some of the ctenophores show the beginning of a worm-like elongation. In the Platyhelminthes this characteristic has definitely become established.

Phylum 5. Nemathelminthes. — Here are found the

so-called threadworms or roundworms (Figure 19). There are approximately eighteen hundred species in the group, many of which have adapted themselves to a parasitic life. The organ systems are built on a higher plane of complexity. The digestive system is of a tubular character, having a distinct anterior opening, the

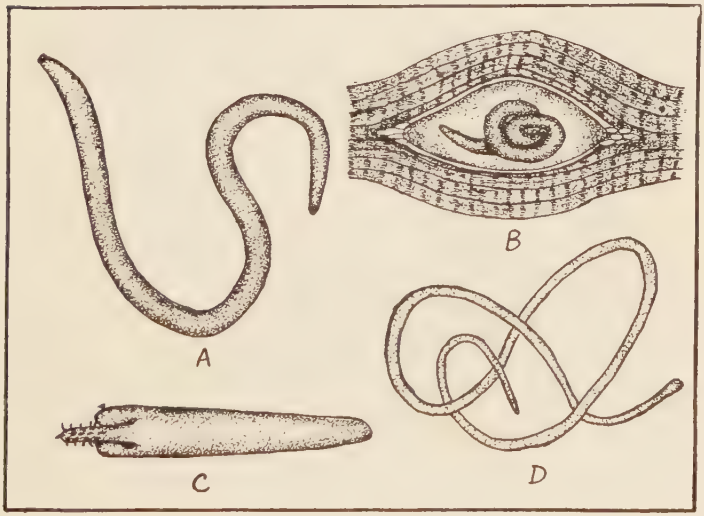


FIG. 19. NEMATHELMINTHES

A, ascaris; B, trichina, or pork worm; C, hook-headed worm; D, horsehair worm.

mouth, and a posterior opening, the anus. The three tissue layers of ectoderm, endoderm, and mesoderm are well established, and a body cavity, comparable in some respects with the cœlom — the true body cavity of the higher animals — first appears. The organization of the roundworms is such that they show little relationship to

the other groups of animals. It is rather difficult to trace their affinities to the lower or higher forms of the animal kingdom. However, they do show the mesoderm more clearly, have a definite body cavity as well as a tubular digestive system, and because of this they are placed a little higher in the evolutionary scale than the flatworms. But it must be admitted that thus far the

FIG. 20. TROCHELMINTHES

(From Pearse, *General Zoölogy*. Courtesy of Henry Holt & Co.)

zoölogists have been baffled by the phylum, and have not been able to fit it very definitely into its logical position on the evolutionary tree.

Phylum 6. Trochelminthes. — These are commonly known as wheel animals or rotifers (Figure 20) and include about five hundred species. All of them are water-dwelling forms that have great powers of resisting unfavorable conditions. During the development of these animals there invariably occurs a typical larval stage known as a trochophore. The fact is that the Trochel-

minthes as adults show an organization little higher than the trochophore larva, and for this reason they are alluded to quite often as trochophore animals. Figure 21A shows a typical trochophore. From an evolutionary standpoint the trochophore is extremely interesting and important, because it is encountered not only here, but also in the phyla Platyhelminthes, Molluscoida, Annelida, and Mollusca. A larva somewhat similar to the

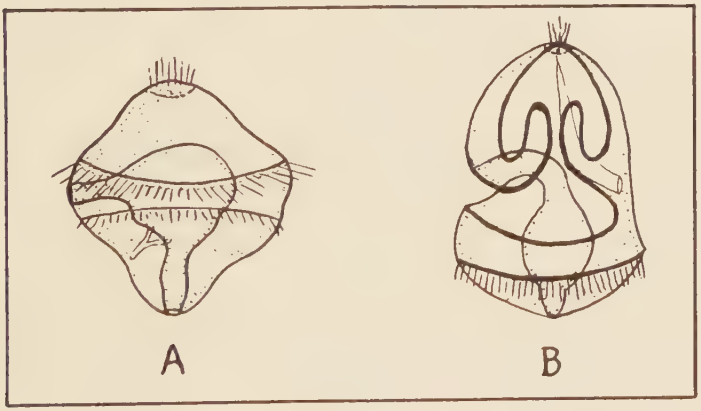


FIG. 21. TROCHOPHORE-LIKE LARVÆ

A, typical trochophore; B, tornaria larva.

trochophore, and yet slightly modified from it, is found in the phylum Echinodermata, as well as in the prevertebrate group to which the worm-like animal Balanoglossus belongs (Figure 21B). This being the case, zoölogists are of the opinion that all of the phyla which show the trochophore larva, or modifications of it, must have evolved from some ancestral form which, as an adult, resembled the trochophore. How this

trochophore-like organism arose, is a debated question; but the prevalent view is that it originated through the ctenophores. Such groups as the Platyhelminthes, Trochelminthes, Molluscoida, Annelida, and Mollusca have undoubtedly been derived directly from this ancestral organism, whereas the echinoderms and the lower chordates, to be discussed later, sprang from a form which became somewhat modified and specialized from the trochophore type.

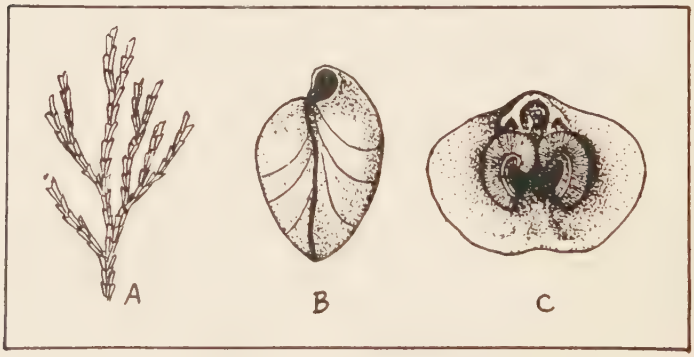


FIG. 22. MOLLUSCOIDA

A, bryozoa; B, brachiopod; C, inner view of brachiopod, showing horseshoe-shaped lophophores.

Phylum 7. Molluscoida. — This phylum (Figure 22) includes a number of divergent species which are found to dwell mainly in the sea. Some are colonial, moss-like animals which form sea mats and are technically called Bryozoa. Others are the peculiar lamp-shells, or Brachiopoda as they are termed, which possess a distinct shell of two valves; because of this characteristic feature they were formerly considered to be allied to

such molluscs as the oyster and clam. Many zoölogists also include in this group numerous small, elongated, worm-like animals which are classified as Phoronida.

All of the Molluscoida agree in that they have a peculiar organ surrounding the mouth, known as a lophophore (Figure 22C), which generally is horseshoe in shape and contains a large number of ciliated tentacles. During embryonic development there is usually a ciliated larva of the trochophore type. A true body cavity, or cœlom, almost always is present, and in most instances there exist one or two pairs of excretory tubes — the so-called nephridia — for the elimination of liquid waste.

Many of the Molluscoida are of great antiquity, as is indicated by the large number of fossils of them which have been discovered. The existing representatives number seventeen hundred species, and most of them are marine forms. The brachiopods, or lamp-shells, are especially interesting, as at one time many thousand species of them existed; but at present the existing representatives include slightly over one hundred types. For some unknown reason they are disappearing and literally dying out.

Phylum 8. Annelida. — This branch of the animal kingdom contains about four thousand species, and here are included many forms such as the earthworms, the sandworms, and the blood-sucking leeches (Figure 23), which are familiar to everybody. The body of the typical annelid is elongated and divided into true ring-like segments which are not mere repetitions of bodily portions capable of functioning more or less by themselves,

but, rather, integral parts of the body of a united organism that functions as a complete entity.

The Annelida embody the most characteristic of invertebrate features, and these may be summarized briefly in the following manner: they possess a slender, tubular digestive system which runs the full length of

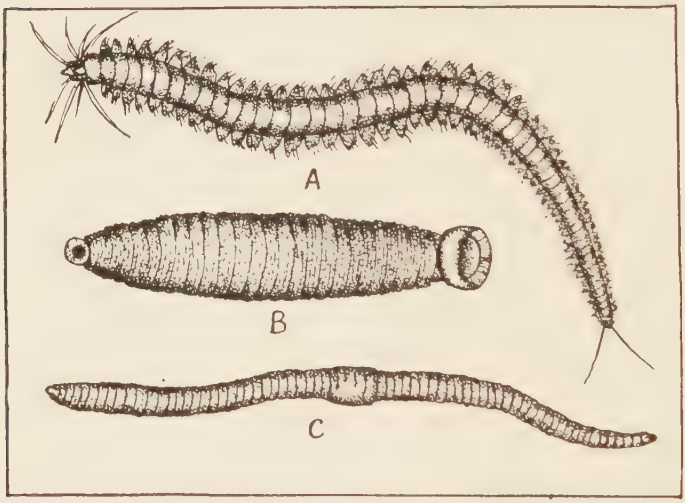


FIG. 23. ANNELIDA

A, sandworm; B, leech; C, earthworm.

the body; a definite cœlomic cavity; many segments called metameres; a nervous system composed principally of an elongated nerve cord running ventral to the digestive tract; and a circulatory system of the open type, in which the flowing blood is partially enclosed in tubular blood vessels for a portion of its course, and then loses itself freely among the body tissues. In the

higher animals, particularly the vertebrates, the circulatory system is of the closed type, that is, the blood is completely enclosed by blood vessels through nearly all of its course within the body. Another characteristic which might be mentioned in connection with the Annelida is that a pair of coiled tubular structures, called nephridia, exists within nearly all of the segments, the function of which is to eliminate liquid wastes from the body. The renal tubules of the kidneys of higher animals are structures showing many striking similarities to the nephridia.

From an evolutionary standpoint it is of interest to note that in the development of many of the Annelida a typical trochophore larva is present, distinctly indicating a definite relationship to other groups of animals where a trochophore is found.

Phylum 9. Echinodermata. — Literally translated, "echinodermata" means spiny skin, and this feature typifies all animals belonging to this phylum. Most of them possess some form of external skeleton which is supplied with hard, spiny projections (Figure 24). Nearly all of them have radial symmetry as adults, and because of this trait the older zoölogists regarded them as being rather simple, and very little above the group to which the jellyfishes belong. However, careful research has shown that the Echinodermata really are quite complicated animals in which radial symmetry must be regarded as a secondary trait of minor importance, for during development practically all of them start out with a distinctly bilateral symmetry. They possess a larva which appears to be a specialized type

somewhat higher in its organization than the trochophore, although closely related to it. Perhaps it is an offshoot which has become so modified and specialized that it bears only a slight resemblance to the trochophore.

There are approximately four thousand species in this group of animals, and they include the different

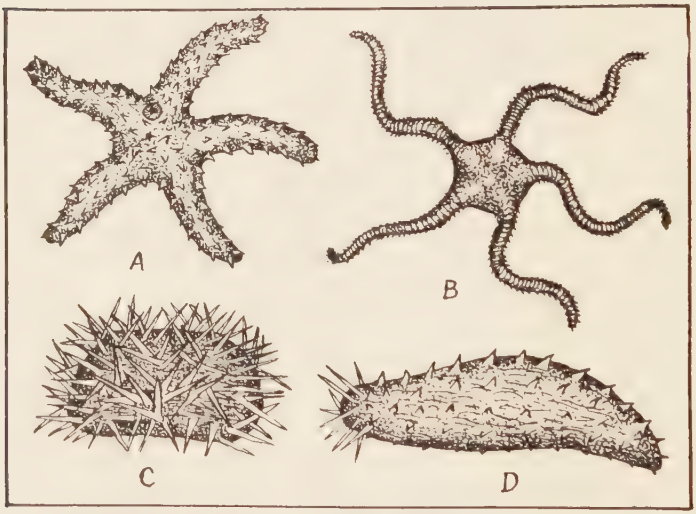


FIG. 24. ECHINODERMATA

A, starfish; B, snaky star; C, sea urchin; D, sea cucumber.

kinds of starfishes that possess rays, varying in number from five to as many as twenty, the brittle or snaky stars, the various sea-urchins, the flattened forms popularly called sand-dollars or sea-cookies, the so-called sea-cucumbers which are elongated and, in many instances, of worm-like appearance, and the graceful sea-

lilies which, like the lamp-shells, are dying out of existence. The accepted view is that this phylum belongs near the annelids and molluscs as far as its complexity and relationship are concerned. However, it must be admitted that there are many points which distinctly separate this group from the others.

Phylum 10. Mollusca. — In this phylum are found some sixty thousand species, showing a great diversity of form and structure, and possessing a certain number of traits in common. They are bilaterally symmetrical animals without any segmentation, and possess no appendages. The cœlom or body cavity is greatly reduced in size, so that it is represented by a very small space. Most of them are provided with some kind of hard shell formed from the mantle which is the outer portion of the skin. In some of the species the shell is minimized or even entirely lacking, and here are included the so-called naked molluscs such as the garden slugs and the sea-dwelling nudibranchs. In animals such as the squid and the octopus the structure that corresponds to a shell is found in the interior in the form of a firm rod. The familiar species are the clams, oysters, scallops, mussels, and snails (Figure 25). These dwell in diverse places, in fresh or salt water, or on land, and are provided with some form of shell consisting either of two valves or of a single valve arranged in straight or spiral fashion.

Many molluscs pass through a larval stage which resembles either the trochophore larva or one a little higher in complexity, and is somewhat similar to the pre-chordate, Balanoglossus, a form regarded as

ancestral to the typical chordates or vertebrates. From an evolutionary standpoint these facts definitely link the molluscs to the other phyla which show the trochophore during embryonic existence. Undoubtedly they sprang from a trochophore-like ancestor. Their behavior, as

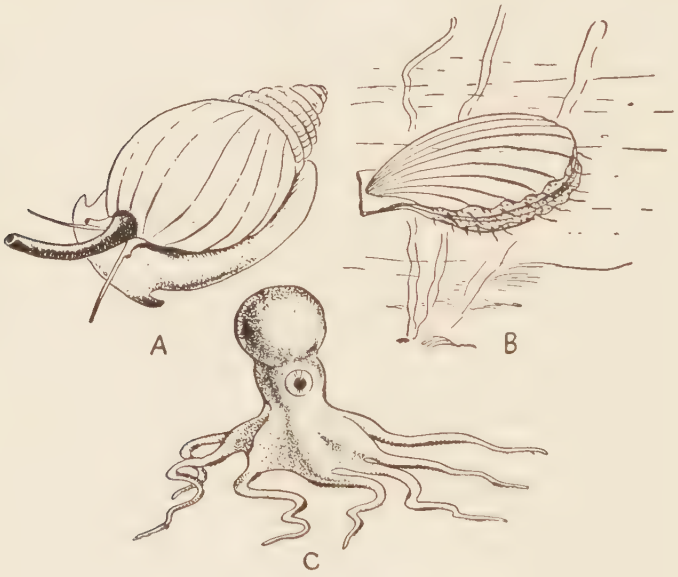


FIG. 25. MOLLUSCA

A, snail; B, scallop; C, octopus. (From Gruenberg, *Biology and Human Life*. Courtesy of Ginn & Co.)

well as their complex structural organization, place them near the top of the list of invertebrates, probably a little higher than the annelids and echinoderms.

Phylum 11. Arthropoda. — The Arthropoda are now regarded as the highest group of invertebrates. The

phylum is extensive, containing between four and five hundred thousand distinct species, this figure outnumbering the entire remainder of the animal kingdom.

The body of the arthropods is bilaterally symmetrical and segmented. Many of the segments bear paired appendages which are jointed and modified in various ways. Invariably they are supplied with an outer skeleton of chitinous material which affords them protection. Their nervous system is built on the typical annelid plan, most of it consisting of a nerve cord under the digestive system. Their circulatory system is of the open type, with a heart that is a single muscular chamber, lying dorsal to the digestive tract, and a system of partially developed blood vessels through which the blood first flows a part of the way and then loses itself freely among the tissues during the rest of its course through the body.

The arthropods dwell on land, in water, or in the air, and have adapted themselves wonderfully to these differing modes of existence. Those found on land or in the air have developed tube-like structures, tracheæ, for breathing purposes. Such worm-like forms as Peripatus, the centipedes and millepedes, and the insects, are in this category. The Crustacea, which dwell in water or in moist places, breathe by means of gills. The remaining representatives of the arthropods, that is, such forms as the spiders, scorpions, ticks, and the extremely interesting king crab, Limulus, are supplied with peculiar organs known as book lungs or book gills, as well as tracheæ, for respiration. Figure 26 shows typical examples of the phylum.

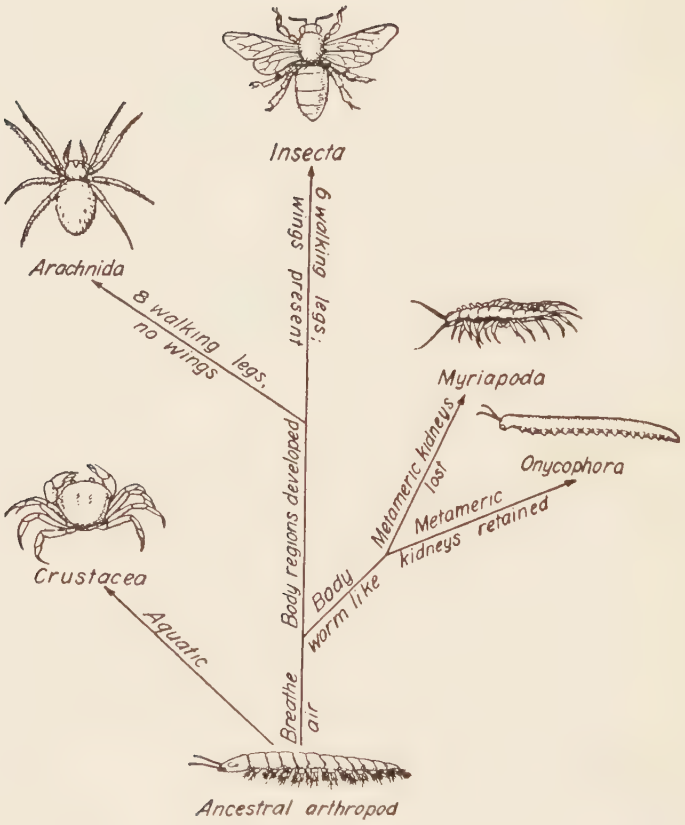


FIG. 26. ARTHROPODA

(From Pearse, *General Zoölogy*. Courtesy of Henry Holt & Co.)

The arthropods exhibit wonderful adaptations as well as remarkable complexity of behavior. In some forms this has gone so far in its development as to bring about social life and many of its ramifications, such as division of labor and specialization.

Practically all of the animals in this phylum undergo a metamorphosis, or transformation, in which they pass through certain larval stages during their development to adult form. Such metamorphosis is seen commonly in the development of a butterfly, in which the fertilized egg stage grows into a worm-like caterpillar and this, after a free existence for some time, becomes quiescent within a cocoon which it builds around itself. Here it remains inactive for a short period and finally emerges as the adult butterfly. It is significant to note that in nearly all such development some worm-like stage, similar to the annelids, is repeated. Furthermore, many of the arthropods as adults are worm-like not only in appearance, but also in organization. The form Peripatus illustrates this in a striking manner. Its tracheæ link it to the arthropods, whereas its paired nephridia show its correlation to the annelids. Facts such as these have led evolutionists to the conclusion that the arthropods undoubtedly have developed as an offshoot from a unit similar to the annelids. Perhaps a group of trochophore-like animals was ancestral to all of the phyla in which a trochophore and worm-like larva are repeated.

2. *Résumé* of Invertebrates

Before taking up the last unit of the animal kingdom, the phylum Chordata, which includes the most highly specialized animals, principally the typical chordates or vertebrates, it may be well for us to enumerate briefly the principal steps doubtless involved in the evolution of the various phyla which we have considered. The

start is made with the minute, microscopic Protozoa, which are either simple, single-celled forms of little differentiation, or colonial forms in which there exists an aggregation of numerous cells, with some degree of differentiation and division of labor. From certain of these latter types the sponges doubtless originated, and here specialization has advanced to the point where two more or less definite layers of cells have been established.

The next step in the evolutionary process was probably that in which the cell layers took on a distinct appearance of tissues, and there arose a two-layered, diploblastic animal resembling a typical gastrula. The phylum Coelenterata, including forms like the jellyfishes and anemones, are animals of this type.

The three-layered or triploblastic, trochophore-like organism followed, and from it the various higher invertebrates arose. This is true not only of the groups in which a typical trochophore is found during embryonic development, but also of such groups as the echinoderms and the primitive chordate, Balanoglossus, where that stage has become so modified that it bears no more than a superficial resemblance to it.

The final step in invertebrate evolution came with the establishment of the segmented, worm-like animal that is represented by the present-day annelids. The arthropods undoubtedly arose as an offshoot from such a type, as may be judged from the numerous worm-like larvæ represented during the development of various members of this phylum.

Summarizing all of the steps in this evolution, we get a single-celled type, a colonial type, a two-layered type

culminating in a typical gastrula, and a three-layered trochophore type, giving origin to all of the higher invertebrates such as the Trochelminthes, Molluscoida, Annelida, Echinodermata, Mollusca, and Arthropoda. One branch diverged in a different direction and undoubtedly produced the last phylum of the animal kingdom, namely, the Chordata, including the most highly specialized animals, the typical chordates or vertebrates, as well as some which are lower in the scale of evolution, the primitive chordates, which show characteristics that bind them, on the one hand, to the invertebrates and, on the other, to the vertebrates.

3. The Phylum Chordata

The phylum Chordata, the twelfth and last of the animal kingdom, contains about thirty-six thousand species. As has been indicated, it comprises two subdivisions, the primitive chordates and the typical chordates, or vertebrates. The former include a number of representatives which are encountered but rarely by the average individual; however, they are extremely important from the evolutionary standpoint in that they bridge the gap between the invertebrates and the vertebrates. The latter, on the other hand, embrace organisms which are familiar to everyone and are considered to be the most complex as well as the most highly specialized animals.

All chordates possess a number of similar characteristics. They have a tough rod called the notochord, which runs in the interior of the body and lies dorsal to

the digestive system. In most instances this structure resembles a stiff jelly in its consistency. In the vertebrates, with the exception of the lowest, the notochord is found only during embryonic development, where it affords the nucleus around which the bony portions of the spinal column are formed; but in the adult organism it is soon absorbed by the surrounding tissue, so that all traces of it disappear completely.

Also, there is to be found in either the adult or the embryonic stages of the chordates a series of paired slits which connect the pharynx of the throat with the exterior. These are technically called " pharyngeal clefts " or " gill slits," and where they are functional, as in fishes and tadpoles, they allow water to pass from the interior of the pharynx to the outside, thereby serving for purposes of respiration. In those chordates which breathe by means of lungs, invariably the clefts are transitory structures which are modified before maturity is reached.

Another general characteristic of the chordates is that the main portions of the nervous system, namely, the brain and spinal cord, are tubular and lie dorsal to the notochord. In the lower types there is little differentiation of the parts of the so-called " neural tube," but in the higher forms, as represented by the various members of the typical chordates, there is specialization into an anterior brain, a posterior spinal cord, and numerous nerves of one kind or another.

The typical chordates or vertebrates also are characterized by the possession of a few other features in common. All of them develop an internal, hard skele-

ton of either cartilage or bone, which is segmented and acts as a supporting framework for the other structures and organs of the body. There is a closed circulatory system, consisting of a chambered heart, a muscular organ lying ventral to the digestive tract, and a complete set of tubular blood vessels which carry the blood to and from the heart proper. In the highest chordates, namely, the birds and mammals, the circulatory system reaches its greatest degree of complexity. Here the blood is warm, maintaining a constant temperature throughout life, whereas in the other vertebrates the blood is cold, its temperature varying with the conditions of the environment.

A final characteristic of nearly all vertebrates is that they possess two pairs of lateral appendages known as limbs. Hand in hand with these structures are found two pairs of limb-girdles, specialized portions of the internal skeleton for attachment and support of the various muscles and bones of the appendages themselves. These latter parts become modified in the direction of the particular need of the organism in question. In fishes they exist as fins for propelling the animal through water; in the amphibians they are feet, which oftentimes are webbed for locomotion on land or in water; in the reptiles they are either degenerate, as in snakes, or specialized into clawed feet for terrestrial or aquatic locomotion; in birds the anterior limbs are modified into wings for flying and the posterior pair is adapted for scratching, tearing, wading, walking, or swimming; and in the mammals either both pairs of limbs become specialized for locomotion in water or on

FIG. 27. TYPICAL CHORDATES OR VERTEBRATES

(From Ritchie, *Human Physiology:* 1920 Revision: Copyright 1920 by World Book Co., Publishers, Yonkers-on-Hudson, New York.)

land, or the posterior pair alone functions in this respect, whereas the anterior pair becomes transformed, as in the bats, into wings for flying, or as in man, into arms for manipulation of food, as well as for protection from enemies. Seven classes of vertebrates are recognized, typical representatives of which are shown in Figure 27.

Class 1. Cyclostomata. — The cyclostomes, as these are called, include two distinct living representatives: the hagfishes, which dwell in muddy bottoms of the ocean; and the lampreys, which live not only in the sea but also in fresh water. Both exist as parasites on true fishes; the former bore their way into the soft interiors of the host, and the latter attach themselves to the surface muscles, gradually working inward for the purpose of sucking blood. The cyclostomes are eel-like in their general appearance, and are supplied with numerous pairs of gill clefts for respiration. The skeleton is membranous and cartilaginous in nature. They possess no paired fins or true jaws, and their only weapon of offense consists of a spiny muscular disc around the mouth, by means of which they attach themselves to a host. The damage they do is accomplished by either the single tooth of the hagfishes or the rasping tongue of the lampreys.

Class 2. Elasmobranchii. — This class includes such fish-like forms as the sharks, skates, and rays. In general form and appearance they closely resemble the true fishes, and therefore many zoölogists are inclined to classify them as such. However, as adults they possess a notochord and a skeleton of cartilage. The skin is tough and covered with pointed scales called placoid

scales. When sections of these are examined under the microscope, it is discovered that they resemble, in general structure, the true teeth of a typical vertebrate.

Class 3. Pisces. — Here are found the true fishes possessing cartilaginous or bony skeletons, with true jaws and fins which are often supported by stiff processes known as fin rays. The true fishes breathe chiefly by means of gills, and the heart is distinctly two-chambered — a condition similar to that found in the cyclostomes and elasmobranchs. The outside of the body usually is covered by a tough skin in which large numbers of stiff structures, known as scales, have developed for purposes of protection.

Class 4. Amphibia. — The various species of frogs, toads, and salamanders belong to this class. The young of these forms usually dwell in water and breathe exclusively by means of gills. The adults, however, live either in water or on land, and breathe by means of the skin or lungs which have replaced the gills. In some adults the gills are retained, so that respiration is accomplished through the skin, lungs, and gills. The skin of Amphibia is smooth and slimy, no scales being present. They possess two pairs of limbs, the so-called fore-limbs and hind-limbs, each supplied with five digits that lack claws. The circulatory system shows a greater degree of complexity, the heart being distinctly three-chambered. Among the Amphibia one meets the first vertebrates that have left their water habitat in order to become definitely adapted to living on land, that is to say, the first terrestrial vertebrates.

Class 5. Reptilia. — In this class are found snakes,

lizards, turtles, and crocodiles. They are covered with a dry, scaly skin and breathe exclusively through lungs. Wherever limbs are developed they are found to be paired structures, with definite claws on the toes. The heart shows higher development, consisting of either three or four chambers. Where the three-chambered condition is encountered, usually there is an indication of a superficial division in one of the compartments, this quite clearly being a step in the evolution toward the four-chambered type, the kind found in the most complex vertebrates, the birds and mammals.

Class 6. Aves. — The numerous varieties of birds comprise this class. They have an outer covering of feathers, and the legs possess scales. The fore-limbs are modified into wings for flying, and the hind-limbs are specialized for walking, running, wading, or swimming, as the environment may demand. Beginning with the birds, we encounter the first vertebrates possessing warm blood and a definite body temperature. The circulatory system has attained a high degree of complexity, and the heart is distinctly four-chambered. The skeleton has been modified in such a way as to aid the animal in its progress through the air. Many of the bones are hollow, being filled with air spaces so as to lighten the weight of the body.

Class 7. Mammalia. — In the mammals, the most complicated of the vertebrates, specialization of organ systems has reached the highest stages of development. There are many kinds of mammals — such as the duck-bills, seals, whales, bats, dogs, elephants, horses, monkeys, and man — but all of them possess similar

characteristics. Either during embryonic life or as adults they are covered with hair; invariably they undergo pre-natal development internally and for some time after birth are suckled by means of milk developed in the mammary glands of the mother. The heart is four-chambered and the blood maintains a constant temperature with little variation throughout life.

In connection with the Mammalia the lowest order of the class, namely, the monotremes, must be mentioned. These really are primitive mammals that have characteristics connecting them with the birds and reptiles. The best known example of the monotremes is the duckbill of Australia. This animal is adapted to an aquatic life. It has webbed feet and is supplied with a duck-like beak, by means of which it burrows in the muddy bottoms of streams for worms and insect larvæ. The female deposits her eggs in an underground nest that extends as a channel beneath the bank, and from them in due course of time the young are hatched. This egg-laying habit, the arrangement of the skeleton, as well as certain structural peculiarities of the internal organs of reproduction, excretion, and digestion, definitely show the duckbill to be closely allied to the reptiles and birds. But the presence of hair and mammary glands establishes its kinship to the mammals. This is truly a transitional type, linking particularized groups.

4. Evolution of Vertebrates

The relationship between the invertebrates and the vertebrates must now be considered, to the end of deter-

mining the manner in which the latter have emerged from the former. Prior to the middle of the nineteenth century, the invertebrates and vertebrates were regarded as two entirely distinct divisions of the animal kingdom, with no possible transitions between them. Since then, however, the so-called primitive chordates have been discovered and carefully studied, with the result that they have been found to possess characteristics which link them to both of these major divisions.

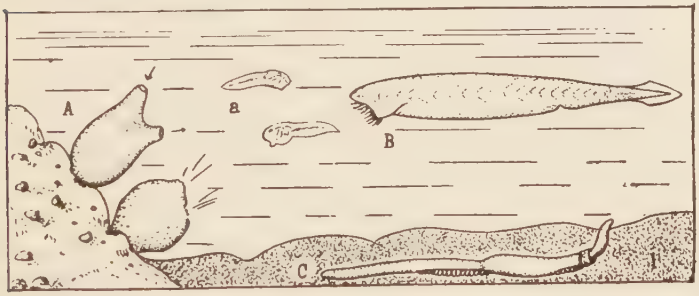


FIG. 28. PRIMITIVE CHORDATES

A, adult sea-squirt; a, larval sea-squirt; B, amphioxus; C, balanoglossus. (From Curtis and Guthrie, *Textbook of General Zoölogy*. Courtesy of John Wiley & Sons, Inc.)

Zoölogists now believe that the primitive chordates are important "missing links" in the chain of animal evolution by means of which the higher forms, the vertebrates, may be distinctly joined to the lower ones, the invertebrates. It is therefore important for us to examine the primitive chordates, so that we may become familiar with the relationships indicated.

The first of the primitive chordates of significance is represented by the form known as Balanoglossus

(Figure 28 C). This is a slender, elongated, worm-like animal which is found dwelling in the sand or mud of the sea. It feeds in similar fashion to the sandworm or earthworm; mud and sand are taken into the digestive tract, the nutriment is extracted, and the solid particles ultimately are passed out through the anus. The animal is divided into three regions: a muscular proboscis at the anterior end, next to it a slender band known as the collar, and the largest division, the trunk region. This last-named portion is distinctly segmented, being similar in its general appearance and make-up to the body of a typical annelid worm.

Balanoglossus also resembles the chordates in many ways. It possesses a short notochord which is produced as an outgrowth of the anterior part of the digestive tract. It has a dorsal as well as a ventral nerve cord, the former being the more prominently developed. Furthermore, numerous gill slits are in evidence in the anterior region of the trunk, each of them running from the pharynx to the outside and opening through a perforation on the exterior surface of the trunk. A firm chitinous bar supports each of these clefts, the whole affording a more or less rigid system of support for the openings. Moreover, during its development Balanoglossus is observed to pass through a larval stage called a tornaria (Figure 21 B), and when this is closely examined it is seen to have many points in common with the larvæ of the echinoderms as well as the trochophore-like larvæ of numerous invertebrates. Such evidence leads to the general opinion, not only that the trochophore was the ancestor of the invertebrates where

it is found to be a part of the normal cycle of embryonic development, but also that one offshoot gave origin to the echinoderms, and another established the pre-chordate group to which Balanoglossus belongs.

The second important branch of the primitive chordates consists of animals commonly called sea-squirts, technically known as tunicates or ascidians (Figure 28 A). They are sessile, marine-dwelling forms which are attached to a variety of solid objects. The adult of the typical tunicate shows little resemblance to the chordates, and receives its name of sea-squirt from its habit of discharging water from two openings when disturbed. The larva, on the other hand, exhibits a striking similarity to the chordates. In general appearance it resembles a tadpole (Figure 28 a), is free-swimming, and possesses a distinct notochord which is confined to the tail region. Above the notochord, and extending almost the full length of the body, is the neural tube, the anterior portion of which is concentrated into a brain. Finally, the pharynx opens to the exterior by means of ciliated gill slits. After a free-swimming existence the larva settles down and becomes transformed beyond recognition into the adult animal.

The third and last of the primitive chordates is represented by the form known as Amphioxus, or the lancelet (Figure 28 B). This is the best known animal of the pre-chordate group and possesses the most typical chordate characteristics. It is a small organism, elongated and fish-like in appearance. It dwells in the sea, either burrowing in the sand or swimming about freely in the

water. The body is divided into external segments by many muscle bands. A notochord extends the full length of the animal, dorsal to the digestive system, and immediately above it is an undifferentiated nerve cord. Amphioxus shows numerous gill slits which, after perforating the pharynx, enter a large common chamber that surrounds them, called the atrium. These slits are supported by stiff chitinous bars similar to those found in Balanoglossus. Water is drawn into the pharynx through the mouth; it then passes into the gill clefts, where the oxygen is extracted and carbon dioxide given off, and finally reaches the atrium, whence it is expelled to the exterior by means of a posterior opening known as an atriopore. Paired limbs are not present in Amphioxus, but many biologists believe that the pair of thick folds, the so-called metapleural folds, which run along the lateral margins of the under surface of the anterior portion of the animal, are the forerunners of the paired limbs of the true vertebrates.

Thus it is seen that this form, as an adult, shows the most characteristic of chordate features, and it is therefore regarded by most evolutionists as the immediate ancestor of the vertebrates. Amphioxus must have originated, in turn, from an organism somewhat resembling the larva of the ascidians. This larva, as will be recalled, is free-swimming and possesses many of the features that are common to both the sea-squirts and the lancelets. There must have existed in ancient times a group of pre-chordates which, as adults, resembled the typical ascidian larva of the present day. From one branch the present tunicates probably originated, and from an-

other the lancelets, and these undoubtedly gave origin to the true vertebrates.

The form which is ancestral to the tunicates and also is transitional between the invertebrates and the chordates is the worm-like animal Balanoglossus. It has been shown that during its development Balanoglossus possesses a tornaria larva, which in many of its features resembles an echinoderm larva as well as a trochophore. Judging from evidence such as this, the evolutionists believe that the trochophore-like ancestor mentioned earlier in this chapter, through one line of specialization, developed the invertebrate phyla such as the annelids, echinoderms, and molluscs, where the trochophore expresses itself as a part of the normal cycle of development; and through another line of differentiation it gave origin to primitive chordate forms such as Balanoglossus, Tunicata, and Amphioxus, the ancestors of the typical chordates or vertebrates. The gap between the invertebrates and vertebrates is thereby bridged, definitely linking the former to the latter by numerous ties.

Thus the evolution of organisms is a continuous progression from the simplest to the highest forms, each step in this successive climb affording a criterion not only of complexity of organization, but also of relationship, which reveals the mode of origin. For example, the organ systems and structures of the vertebrates show an almost perfect evolution. Take, for instance, the skeleton. In the lowest forms it exists as a membranous or cartilaginous structure; in the true fishes it becomes more ossified in texture and remains so in

those classes of animals from the amphibians to the mammals, inclusive. It is also interesting to note that in these latter forms, where the adult animal possesses a skeleton of true bone, this is produced during embryonic development through a transformation that involves three distinct stages: first, certain of the cells are aggregated into a tough membrane; next, by deposits of salts, particularly those of calcium and phosphorus, this membranous stage is converted into a cartilaginous one, and ultimately, by additional deposits, the bony skeleton is formed. In the case of the bones of the upper portion of the head, the so-called cranial bones, it has been found that they form directly from the membranous stage. Here the cartilaginous phase is omitted.

The circulatory system shows a somewhat similar progression. In the primitive chordates the heart consists of a single chamber, which in reality is an enlarged blood vessel; in the lowest of the vertebrates there is a two-chambered heart; in the Amphibia, and in most of the Reptilia, a three-chambered heart appears; and finally, in the highest of the vertebrates a four-chambered heart. In studying the development of all animals which, as adults, possess a four-chambered heart, we discover that this organ undergoes a pre-natal evolution similar to that which has been indicated for the heart of the various classes of vertebrates. It starts as an enlarged blood vessel, which through a folding and dividing process becomes transformed successively into a two-, three-, and four-chambered organ.

An unfoldment just as striking and significant as any

of the above may be indicated for many of the other organ systems of the vertebrates. There are, of course, numerous questions in connection with this evolution which cannot be answered positively, but the fundamental plan of vertebrate organization is so clear, and shows so many points of remarkable similarity in structure and development, that it cannot be interpreted in an intelligent manner on any save the evolutionary basis.

CHAPTER VI

EVIDENCE FOR ORGANIC EVOLUTION

The evidences for the evolution of living organisms are numerous, and they are indelibly inscribed in the record of the past and present expressions of terrestrial life. The biologist recognizes them everywhere about him, and as time goes on he is constantly discovering additional facts to substantiate the story of the continuous progression of animal and plant life. Although these evidences in a large measure are circumstantial in character, it is none the less true that they are so strong and so varied as to be regarded, by those who have carefully examined them, as conclusive proof for the gradual emergence of life upon the earth, from the most elementary to the most involved forms.

The average person often does not recognize these evidences, for he regards proof as something to be obtained directly within the laboratory, during an exceedingly short period of time; and to him time is measured in terms of his own span of existence. Not so with the scientist. His studies have led him to look upon change and transformation as the product of long stretches of time measured in terms of thousands, millions, and even billions of years. How insignificant, comparatively, becomes the average length of human life!

It is questionable whether even a very slight trans-

formation can be perceived in fifty or a hundred years. The change is produced so gradually that, though it may have been going on during an average lifetime, it could be overlooked entirely, except, of course, by those individuals who, through a careful study of nature, have become aware of the modifications which took place in past generations. Throughout these past ages nature has been experimenting, bringing forth one group of organisms after another, each adapted to the specific conditions of the times in which they came into existence. When the surroundings changed, those forms which had become so highly specialized that they could not adjust themselves in a corresponding manner soon became extinct, and were superseded by types better fitted to cope with the altered conditions of the new environment.

Laymen often ask why the scientist cannot repeat the evolutionary processes within the laboratory. In response to this query it must be pointed out that until the present time science has not been able to reproduce the conditions and factors which existed in past generations during which the process of evolution was going on, because they are not fully known; and even if the creation of such conditions in a laboratory became possible, it is questionable whether any scientist, or even a group of scientists could carry on continuous experiments over the long periods necessary to bring about those variations which were essential for the establishment of permanent species upon the earth. Therefore science falls back on the evidence at hand, which, as already indicated, is found in great abundance

everywhere about us. True, this evidence is largely circumstantial in character, but as Huxley many times pointed out in his debates on evolution, if a jury in a court of law finds circumstantial evidence convincing, it does not hesitate to convict on the strength of it.

In his third lecture to workingmen,[1] Huxley deals with the manner in which science arrives at its conclusions, and in his very characteristic manner he points out that the process is similar to that by which the average person ordinarily arrives at conclusions. A few paragraphs from this lecture will set forth his point of view:

I want to put the case clearly before you, and I will therefore show you what I mean by another familiar example. I will suppose that one of you, on coming down in the morning to the parlour of your house, finds that a tea-pot and some spoons which had been left in the room on the previous evening are gone, — the window is open, and you observe the mark of a dirty hand on the window-frame, and perhaps, in addition to that, you notice the impress of a hob-nailed shoe on the gravel outside. All these phenomena have struck your attention instantly, and before two seconds have passed you say, " Oh, somebody has broken open the window, entered the room, and run off with the spoons and the tea-pot! " That speech is out of your mouth in a moment. And you will probably add, " I know there has; I am quite sure of it! " You mean to say exactly what you know; but in reality you are giving expression to what is, in all essential particulars, an hypothesis. You do not *know* it at all; it is nothing but an hypothesis rapidly framed in your own mind. And it is

[1] *Darwiniana,* New York, D. Appleton & Co., 1898.

an hypothesis founded on a long train of inductions and deductions.

What are those inductions and deductions, and how have you got at this hypothesis? You have observed, in the first place, that the window is open; but by a train of reasoning involving many inductions and deductions, you have probably arrived long before at the general law — and a very good one it is — that windows do not open of themselves; and you therefore conclude that something has opened the window. A second general law that you have arrived at in the same way is, that tea-pots and spoons do not go out of a window spontaneously, and you are satisfied that, as they are not now where you left them, they have been removed. In the third place, you look at the marks on the window-sill, and the shoe-marks outside, and you say that in all previous experience the former kind of mark has never been produced by anything else but the hand of a human being; and the same experience shows that no other animal but man at present wears shoes with hob-nails in them such as would produce the marks in the gravel. I do not know, even if we could discover any of those "missing links" that are talked about, that they would help us to any other conclusion! At any rate the law which states our present experience is strong enough for my present purpose. You next reach the conclusion, that as these kinds of marks have not been left by any other animals than men, or are liable to be formed in any other way than by a man's hand and shoe, the marks in question have been formed by a man in that way. You have, further, a general law, founded on observation and experience, and that, too, is, I am sorry to say, a very universal and unimpeachable one, — that some men are thieves; and you assume at once from all these premises — and that is what constitutes your hypothesis — that the man who made the marks outside and on the window-sill opened the

window, got into the room, and stole your tea-pot and spoons. You have now arrived at a *vera causa;* — you have assumed a cause which, it is plain, is competent to produce all the phenomena you have observed. You can explain all these phenomena only by the hypothesis of a thief. But that is a hypothetical conclusion, of the justice of which you have no absolute proof at all; it is only rendered highly probable by a series of inductive and deductive reasonings.

I suppose your first action, assuming that you are a man of ordinary common sense, and that you have established this hypothesis to your own satisfaction, will very likely be to go off for the police, and set them on the track of the burglar, with the view to the recovery of your property. But just as you are starting with this object, some person comes in, and on learning what you are about, says, "My good friend, you are going on a great deal too fast. How do you know that the man who really made the marks took the spoons? It might have been a monkey that took them, and the man may have merely looked in afterwards." You would probably reply, "Well, that is all very well, but you see it is contrary to all experience of the way tea-pots and spoons are abstracted; so that, at any rate, your hypothesis is less probable than mine." While you are talking the thing over in this way, another friend arrives, one of that good kind of people that I was talking of a little while ago. And he might say, "Oh, my dear sir, you are certainly going on a great deal too fast. You are most presumptuous. You admit that all these occurrences took place when you were fast asleep, at a time when you could not possibly have known anything about what was taking place. How do you know that the laws of Nature are not suspended during the night? It may be that there has been some kind of supernatural interference in this case." In point of fact, he declares that

your hypothesis is one of which you cannot at all demonstrate the truth, and that you are by no means sure that the laws of Nature are the same when you are asleep as when you are awake.

Well, now, you cannot at the moment answer that kind of reasoning. You feel that your worthy friend has you somewhat at a disadvantage. You will feel perfectly convinced in your own mind, however, that you are quite right, and you say to him, "My good friend, I can only be guided by the natural probabilities of the case, and if you will be kind enough to stand aside and permit me to pass, I will go and fetch the police." Well, we will suppose that your journey is successful, and that by good luck you meet with a policeman; that eventually the burglar is found with your property on his person, and the marks correspond to his hand and to his boots. Probably any jury would consider those facts a very good experimental verification of your hypothesis, touching the cause of the abnormal phenomena observed in your parlour, and would act accordingly.

Now, in this suppositious case, I have taken phenomena of a very common kind, in order that you might see what are the different steps in an ordinary process of reasoning, if you will only take the trouble to analyse it carefully. All the operations I have described, you will see, are involved in the mind of any man of sense in leading him to a conclusion as to the course he should take in order to make good a robbery and punish the offender. I say that you are led, in that case, to your conclusion by exactly the same train of reasoning as that which a man of science pursues when he is endeavouring to discover the origin and laws of the most occult phenomena. The process is, and always must be, the same; and precisely the same mode of reasoning was employed by Newton and Laplace in their endeavours to

discover and define the causes of the movements of the heavenly bodies, as you, with your own common sense, would employ to detect a burglar. The only difference is, that the nature of the inquiry being more abstruse, every step has to be most carefully watched, so that there may not be a single crack or flaw in your hypothesis. A flaw or crack in many of the hypotheses of daily life may be of little or no moment as affecting the general correctness of the conclusions at which we may arrive, but, in a scientific inquiry, a fallacy, great or small, is always of importance, and is sure to be in the long run constantly productive of mischievous, if not fatal, results.

Do not allow yourselves to be misled by the common notion that an hypothesis is untrustworthy simply because it is an hypothesis. It is often urged, in respect to some scientific conclusion, that, after all, it is only an hypothesis. But what more have we to guide us in nine-tenths of the most important affairs of daily life than hypotheses, and often very ill-based ones? So that in science, where the evidence of an hypothesis is subjected to the most rigid examination, we may rightly pursue the same course. You may have hypotheses and hypotheses. A man may say, if he likes, that the moon is made of green cheese: that is an hypothesis. But another man, who has devoted a great deal of time and attention to the subject, and availed himself of the most powerful telescopes and the results of the observations of others, declares that in his opinion it is probably composed of materials very similar to those of which our own earth is made up: and that is also only an hypothesis. But I need not tell you that there is an enormous difference in the value of the two hypotheses. That one which is based on sound scientific knowledge is sure to have a corresponding value; and that which is a mere hasty random guess is likely to have but little value. Every great step in

our progress in discovering causes has been made in exactly the same way as that which I have detailed to you. A person observing the occurrence of certain facts and phenomena asks, naturally enough, what process, what kind of operation known to occur in Nature applied to the particular case, will unravel and explain the mystery? Hence, you have the scientific hypothesis; and its value will be proportionate to the care and completeness with which its basis had been tested and verified. It is in these matters as in the commonest affairs of practical life: the guess of the fool will be folly, while the guess of the wise man will contain wisdom. In all cases, you see that the value of the result depends on the patience and faithfulness with which the investigator applies to his hypothesis every possible kind of verification.[2]

The circumstantial evidence existing in nature that substantiates evolution is so strong and so conclusive that all fair-minded observers have accepted it. The various lines of evidence for the evolution of organic life will be discussed as follows:

1. Evidences from the distribution of animals, from the standpoint of time and place. The former kind of distribution is called geological, the latter geographical.

2. Evidences from morphology, embracing those which deal with the fundamental form, structure, and composition of organisms. These are usually grouped under the headings of comparative anatomy and serology.

3. Evidences from embryology, or those dealing with the comparative development of individuals before birth.

[2] *Idem*, pp. 368–375.

4. Evidences from experimental biology, dealing mainly with the discoveries in the field of genetics. These facts will be related in the subsequent chapters in which the basic and causal factors of evolution are discussed.

CHAPTER VII

EVIDENCE FROM ANIMAL DISTRIBUTION

Animals are distributed widely from the standpoint of time and place. In spite of the fact that individual organisms have been dying for countless generations, living forms have continued to exist and have carried on the traits inherent in the ancestors which preceded them. The study of the history and distribution of the life of past generations is embraced in geology; that of the present distribution is classified as geography. Both of these fields contribute evidences toward evolution.

1. Geological Distribution

The geological evidences for organic evolution deal with the past history of the earth's life, as revealed by the preserved remnants of animals and plants found embedded in the various strata, or layers, of rock. The study dealing particularly with this past history of life is called paleontology, and the preserved remnants themselves are known as fossils. Fossils, therefore, represent to the geologist a record of animal or plant life, revealed through the preservation of actual remains, or merely impressions of parts of organisms in the rock formations of the earth. Fossils were occasionally discovered prior to the nineteenth century, but scientists

discarded them as mistakes of the Creator which He had buried in the depths of the earth so as not to confuse the great plan of creation. Since the nineteenth century so many of these " mistakes " have been uncovered that scientists refuse to accept such an explanation and now interpret them as organisms which existed upon the earth at some previous time, and which, through some fortunate combination of circumstances, have been permanently preserved. The paleontologist believes that the fossils tell us the interesting history of the life which existed in bygone ages.

In a preceding chapter, the present phyla of animals were discussed from the standpoint of their complexity and sequence of evolution. Zoölogists believe that the animals came into being in the manner there outlined. The geological record strengthens this view and points definitely to the conclusion that life upon the earth has been a distinct progression from the simple to the complex. In a consideration of this history of organic life the fact must be emphasized that the record is inadequate and incomplete, because only a very few of the organisms which have lived upon the earth have been preserved in the rocks, the vast majority of them having left no record at all. Many paleontologists have asserted that not more than one per cent of the types which lived in past generations have been preserved in the form of fossils.

The reasons for this become obvious when the conditions necessary for fossilization are considered. In the first place, the soft parts of animals are rarely, if ever, preserved, so that organisms which did not possess

any hard structures were completely obliterated. Again, in those layers of the earth which consist of the metallic, igneous, and lava rocks, no portions of animals have been found, due, undoubtedly, to the intense heat engendered during or after the production of such formations. Fossils have been discovered almost exclusively in those strata which have been formed through a process of sedimentation, resulting mainly from the slow accumulation of particles of sand, mud, lime, and clay on the bottom of water areas. Animals which died in localities where such action was going on might have found their way to the lower depths of the water where the cold temperature would prevent disintegration of the tissues, while at the same time the constant accumulation of particles of earth would completely cover them and thus preserve their parts intact. Occasionally the organic structures of the animal or plant were replaced by inorganic salts so that they became petrified. Other regions favorable for fossilization are those of intense cold, like deep water basins or glaciers, and those where sticky substances such as oil, tar, and amber have accumulated. Some of the most perfect fossils ever found were discovered in such localities. Huge mammoths have been excavated from the ice in the frozen tundras of the north, and perfect skeletons of numerous mammals have been recovered from the Rancho La Brea tar-pits in the city of Los Angeles. In the amber fields of the area bordering the Baltic Sea many fossils of insects have been found faultlessly preserved. Not infrequently casts or impressions of animals have been discovered, and although these are not the actual

remains of organisms, they nevertheless reveal a great deal concerning the plants or animals responsible for making them. Most paleontologists include casts and impressions as true fossils, and it is interesting to note that many of these imprints have been left in soft formations such as mud, sand, and clay.

This fossil record is extremely fragmentary, but science regards it as ineffaceable evidence in favor of the evolution of life. How long life has existed on the earth, is a debated question; but competent authorities are of the opinion that the period must be measured in terms of many millions of years. Some hold that it stretches over a span of at least five hundred million years, while others carry it considerably beyond this estimate, calculations varying from half a billion to a billion and a half. Conservative estimates regard life upon the earth as having come into existence about one billion years ago, and in the deposits made during the last half-billion years there are definite indications of continuous life, as shown by specific fossils discovered in the various strata which make up the crust of the earth.

The age of the earth as a solid body has been considered in the chapter on inorganic evolution, where it was indicated how the computation was made. The first estimates were based largely on processes of sedimentation, but the most recent ones are due mainly to the results obtained from the newer discoveries in the field of radio-activity. By comparing the fossils of animals or plants with the age of the rocks in which they were discovered, the scientist has been able to tell approxi-

mately when the fossil organisms lived. Even with due allowance for the discrepancies which exist between the different methods of calculating the age of the earth, it remains certain that the existence of life upon the earth covers a very long period — many millions of years.

Geologists have developed a time scale of the past history of the earth and of the organic life produced thereon, and a careful study of this table reveals the astonishing fact that complexity of life has kept pace with the complexity of the non-living environment. As the earth underwent its cycle of evolution, so the life which appeared upon it underwent a similar cycle of evolution, from simplicity to higher complexity, until the present forms were reached. Figure 29 gives a concrete idea of the geological time scale. It shows the various eras, periods, time duration, land formations, and animals which came into existence during the cycle of the earth's evolution from the moment when life made its appearance. In each instance the time element has been computed on the newer basis of the condition of the radio-active minerals in the particular strata in question.

Biologists are convinced that life did not appear until the atmosphere, land, and waters were quite definitely established. The first land formations undoubtedly were metallic and lava-like in character, due largely to the tremendous action and interaction of the hot masses comprising the earth. As solidification set in, brought about largely by the agencies of cooling and condensation, the combined action of the waters and the

Eras	Periods	Age in Millions of Years		Land Formations	Types of Fauna
		Duration	From Present		
Psychozoic or *Quaternary* (Era of man)	Recent	0.3	0.3	Alluvium Peat Clay etc.	Modern man.
	Pleistocene	0.7	1		Paleolithic and Neolithic races of man.
Cenozoic or *Tertiary* (Era of mammals)	Pliocene	6	7	Clays	Ape-men of Java.
	Miocene	12	19		Anthropoid apes and apes.
	Oligocene	16	35		Mammals abundant. Many now extinct.
	Eocene	20	55		
Mesozoic or *Secondary* (Era of reptiles)	Cretaceous	65	120	Chalk	Toothed birds; first snakes; bony fishes abound.
	Jurassic	35	155	Sandstone	Flying reptiles; crocodiles; clams and snails abundant.
	Triassic	35	190	Magnesian limestones	First mammals (Monotremes and marsupials); bony fishes appear.
Paleozoic or *Primary* (Era of invertebrates and lower vertebrates)	Permian	25	215		Earliest true reptiles.
	Carboniferous	85	300	Coal deposits	First amphibia.
	Devonian	50	350		Fishes — elasmobranchs; dipnoi and ganoids.
	Silurian	40	390	Flags Slates Shales Limestones etc.	First air-breathing (terrestrial) animals. First insects; mailed fishes; corals and cephalopods.
	Ordovician	90	480		First known fishes; Brachiopods; trilobites; mollusks, etc.
	Cambrian	70	550		Rhizopods, sponges; corals; worms; crustacea, etc. (Invertebrates only).
Archeozoic and *Proterozoic*	Pre-Cambrian	950	1500	Igneous and Laval	Simple marine invertebrates. Fossils extremely rare.

Fig. 29. Geologic Time Table

atmosphere caused weathering of the land, so that the particles thus formed were carried into the low places and there deposited in the form of sedimentary layers. At first this sedimentation must have been an extremely slow process, but later on, as the atmosphere and hydrosphere assumed more definite shape, it probably took place more rapidly, so that the sedimentary layers produced at this time show a fine texture and more uniform appearance. The activities of the earth, however, continued to go on, and periodically the earth's crust became transformed. Folding, elevation, and depression of various regions resulted. In some places the layers became fractured and turned from a horizontal plane to an inclined or vertical one, enabling the geologist to measure accurately the dimensions of these various deposits. When all of them are pieced together they form a column the mean thickness of which averages about fifty-three miles, the maximum reaching nearly sixty-seven miles.

It is mostly within these sedimentary layers that remnants of ancient life in the form of fossils have been discovered, and with the aid of these the paleontologist has pictured pre-existent life. This is indicated clearly in the geologic time scale (Figure 29). Each era must be considered as a major division embracing a space of time in which definite groups of organisms became established. The era, in turn, contains a number of periods, and each of these corresponds to the particular type of land formation produced during that special span in geologic history. The name of the period, in most instances, has been derived from the inhabitants

of the special place or the actual locality where the formation was first discovered. Bearing this in mind, we may proceed to a brief analysis of the geologic time scale of organic evolution.

Archeozoic and Proterozoic Eras. — These are, respectively, the first and second eras, covering probably a billion years. It is believed that during this time life originated and definitely evolved until the simplest of the marine invertebrates were produced. Fossils, save those of a few hard parts of algæ, protozoa, and worms, are almost unknown in the land formations deposited during these eras. The formations themselves were largely igneous and laval, with a slight degree of coarse sedimentation. The combined thickness of the strata deposited in these eras has been estimated to be about thirty-two miles, whereas the total thickness of the layers deposited during all of the remaining eras has been placed at twenty-one miles, indicating that the Archeozoic and Proterozoic eras occupied a relatively long time, probably over half the period of the existence of life upon the earth.

It was during the Archeozoic era, most students assert, that protoplasm and the earliest living combinations appeared. These were the most primitive units of living matter, and after considerable reaction and adjustment permanent and more or less stable organisms were gradually established. During the Proterozoic era the simple forms which survived from the former age became differentiated and developed into more complex types, until the simpler marine invertebrates were produced. As already indicated, no fossils of animal or

plant life, except the few mentioned above, have been discovered in the strata of these two eras, and this is undoubtedly due, in great measure, to the following factors. First, during the formation of the igneous and lava-like rocks, excessive heat was probably engendered, and it is inconceivable that the simple life which dominated the times survived such conditions. Second, these undifferentiated living forms probably were entirely soft organisms, possessing none of the hard parts necessary for the process of fossilization. Paleontologists, however, are quite sure that life became established during these early eras, because, aside from the few fossils which have been found, there are many evidences of more complex life in the sedimentary layers which follow them. On this basis, they argue that simple organisms must have preceded the more complicated ones, and therefore must have existed in the first two eras in question.

Paleozoic Era. — The third era, the Paleozoic, produced the definite establishment of the invertebrates and the lower vertebrates, particularly the fishes. The era covers a span of approximately three hundred and sixty million years, and embraces six distinct periods.

In the earliest one, known as the Cambrian period, the existent animal life included rhizopods, protozoan-like organisms similar to the amœba, many of which possessed hard shells, and sponges, corals, worms, and crustacea. This is the period in which large numbers of invertebrates flourished and some of them became definitely established. The second period, the Ordovician, shows evidences of brachiopods, trilobites,

molluscs, and the first known fishes. The latter were rather primitive in character. The trilobites were segmented forms bearing resemblances to the modern annelids and arthropods, and are now entirely extinct. The Silurian period followed, during which all the invertebrate groups were definitely established. Here evidences of the existence of the first truly terrestrial and air-breathing organisms are found. The first insects also are included, as are fishes encased in an armor of heavy protective scales. In the next period of the Paleozoic era, namely the Devonian, many of the cartilaginous fishes are encountered, most of them shark-like in appearance. During the last periods, the Carboniferous and Permian, the first amphibians and the earliest reptiles came into existence. Their fossils are discovered in the deposits of coal and magnesium limestone of the particular times in question.

The Paleozoic era is one of considerable importance, covering an age of long duration, in which large numbers of organisms appeared upon the earth. Nature was experimenting; group after group emerged and remained for some time, until the changed circumstances of the environment interfered with their functions to such an extent that ultimately they became extinct. Those which survived became the ancestors of the groups of organisms which resemble them at the present time. The various units of the invertebrate kingdom were evolved; thus also, the foundations for the evolution of the higher vertebrates were laid, as is evidenced by the development of the primitive fishes, amphibians, and reptiles.

Mesozoic Era. — The fourth era of the geologic time scale, the Mesozoic, is believed to have covered a span of about one hundred and thirty-five million years. This era is marked by sandstone and chalk deposits, and the organisms which attained both great size and diverse development were the reptiles. In the early portion of the Mesozoic, namely, the Triassic period, there are evidences that the true or bony fishes and the most primitive of the mammals, the monotremes, appeared. Also the reptiles began to attain gigantic sizes and remarkable proportions, with huge clawed limbs, for progression either on the swampy earth or in water, as well as for protection from enemies.

In the next period, the Jurassic, the reptiles attained their greatest size, and many of them developed large membranous wings, like those of a bat, adapted to a soaring or gliding flight. There also were crocodiles in considerable numbers. These giant reptiles began to deteriorate toward the last of the Mesozoic era, when the period known as Cretaceous set in, and finally they gave way to the true snakes and toothed birds. In this period the bony fishes also are found in great numbers.

Cenozoic Era. — This is the era in which the true birds and the mammals were definitely established. All of the known types of mammals underwent rapid evolution, including the browsing, grazing, and carnivorous forms. This era embraces five periods, extending over about fifty-four million years, and it is characterized by deposits of peat, clay, and alluvium.

During the Eocene, Oligocene, and Miocene periods, many mammals of all kinds, including such forms as

the anthropoid apes and the true apes, were found in abundance; but toward the end of the Miocene period large numbers of these became extinct, leaving only those which became the progenitors of the types found at the present time. In the last period of the era, known as the Pliocene, many of the modern mammals as well as the ancestors of man became established. Traces of the race called the ape-men of Java have been discovered in strata which were deposited near the end of the period.

Psychozoic Era. — The last era to be mentioned, embracing approximately a million years, is known as the Psychozoic or Quaternary. This era includes two periods, called respectively the Pleistocene and the Recent.

The Pleistocene is the period in which the modern mammals and the various races of human individuals, such as the ape-men of Java, Paleolithic, Neolithic, and modern man, came into being. It was marked by a wholesale extinction of many forms and a survival of the types possessing greater powers of nervous response and coördination between themselves and the environment.

The Recent period covers the last thirty thousand years, and is known as the Age of Reason. During this time modern man evolved and developed those nervous faculties, particularly the reasoning ones, which set him apart from the rest of the animal kingdom as the highest product in the evolutionary scheme of creation. Although in nearly all respects man resembles the lower animals, nevertheless the little intelligence which he has evolved has given him a great advantage over all of

them. Incidentally, it has led evolutionists to hope that from modern man there will develop, in future years, a race of supermen possessing nervous systems of greater complexity, with better powers of adjustment and a larger degree of intelligence, to solve the numerous riddles of the universe.

Thus it is seen that the story of the past record of life upon the earth checks admirably with that of the present life. It reveals the progressive steps by means of which the simple animals transformed into the more complex animals until the present types originated. It must be emphasized that while certain of the higher forms were undergoing change, many of the lower ones already were established, and most of these continued their existence with but slight modifications. The record of the vertebrates is perhaps more complete than that of other animals. This is due, in large measure, to the fact that these organisms possessed hard internal skeletons of bone which could withstand the vicissitudes of the transforming environment, and thereby become permanently preserved for future generations. Complete records of many of the existing vertebrates, showing a continuous evolution from earlier to present forms, are to be found. Some of the best known instances of these are the histories of such familiar animals as the modern horse, the camel, and the elephant. Furthermore, the evolution of man is gradually being worked out from the fossil records which have been unearthed, particularly within the last seventy-five years. These fossils have revealed so much concerning man's ancestry that it is not far-fetched to state emphatically

that in the near future the paleontologist will be able to trace man's history as completely as that of any of the well-known forms which have been mentioned.

2. The Evolution of The Horse

The most complete record which has ever been worked out among vertebrates is that which deals with the evolution of the modern horse. The history of this useful animal is so perfect that even without any training in science one can easily follow the changes which have taken place. Fossils of horses have been collected for the past hundred years, and during the last thirty so many type-examples have been found that the evolution of the horse has passed from the realm of uncertainty to that of reality. Scientists and others who are willing to examine the record without prejudice have no doubts as to the facts in the case. They afford a direct proof of evolution. The principal stages in this unfoldment were outlined fifty years ago, particularly by a number of American paleontologists. Although in more recent years these early conclusions have been slightly modified, thanks to the discovery of many additional fossil horses, they have nevertheless, in broad outline, been largely substantiated, so that at present the record of the emergence of the modern horse is one of the classic examples of evolution.

Still, there are some individuals who completely shut their eyes to such disclosures! A short time ago the president of a denominational college delivered a lecture in which he attacked evolution and stated that it

was neither a good theory nor a proven principle. In substantiation of his contention he said that he once visited a large museum in a well-known American university, and there became interested in some plaques on which was traced the evolution of various objects. One of them showed the development of firearms from primitive to modern types, and he commented that it was perfectly easy to follow it. On another plaque was indicated the evolution of the violin, and here again, he asserted, it was a simple matter to follow its development through logical steps until the modern violin was reached. In another room were shown additional plaques dealing with the evolution of certain animals, including forms such as the horse and man. Then this president paused and shook his head, accompanying the gesture with the rhetorical assertion: " I called a halt as far as living organisms were concerned. I could not see such an evolution! " After another moment he exclaimed, amidst considerable laughter from his audience: " Think of it, from the jawbones of an ass, and the shinbones of a monkey, our scientists want us to believe that modern horses and men have evolved! " It is difficult to conceive how anyone who is willing to study the evidences for the evolution of many of our modern animals, particularly the horse and man, as revealed through fossil findings of ancient ancestors, can fail to be convinced of their total validity; for where the record is adequate, these evidences are just as definite as those showing the evolution of violins and firearms.

Concerning the development of the modern horse,

two very interesting contributions have appeared recently: one, a volume by Dr. Frederick B. Loomis [1] of Amherst College; the other, an article by Dr. W. D. Matthew,[2] former paleontologist of the American Museum of Natural History. Both of these authors demonstrate most conclusively that this interesting animal has evolved from a small, four-toed form, no larger than a fox terrier, to the present tall type, with one toe developed particularly for speed. While in general the facts disclosed by Drs. Loomis and Matthew agree with those of the earlier investigators, there are some differences based on a large mass of new and unpublished material which has been collected during the last few years by the various expeditions from Amherst College and the American Museum of Natural History.

Matthew, in interpreting the evidences on the evolution of the horse, says:

> The fossils, found in a certain sequence of geologic formations, are the actual remains of animals that lived when that succession of formations was being deposited. They are a direct record of the geological history of the equine family, that is, of the animals anatomically related to the existing horses. There is no question about the succession of the formations; they have been traced across country, one overlying or overlapping another in such fashion that the sequence is certain. There is no question that the various stages are found in their appropriate position in the geological succession as recited above, and are found only within those limits as specified. This is proved by many thousands

[1] *The Evolution of the Horse,* Boston, Marshall Jones, 1926.

[2] "The Evolution of the Horse," *Quarterly Review of Biology,* vol. 1, (1926), pp. 139–178.

of specimens of the better known stages and by hundreds of nearly all the rarer stages, which have been found by various collecting parties during the last eighty years, especially during the last two decades, and are preserved in various museums, each with exact record of formation and locality in which it was found. Collectors have been keenly on the lookout for exceptions, for such exceptions would be of extraordinary interest to science; but they have not been found. Even certain *apparent* exceptions when more carefully studied have been found not to be real exceptions.

Broadly speaking, the evolution of the horse in the sense of a regular progression by gradual stages from small primitive four-toed ancestors to the large, highly specialized one-toed horse, appears not as a theory but a fact of record. It is equally a fact of record that the tapir and rhinoceros are derived from the same primitive stock through a similar series of progressive stages. Widely different in appearance and habits today, they have diverged from a common ancestral stock.

If, therefore, we turn to the record of geologic history to answer the question whether as a matter of fact the diverse types of existing animals did evolve from common primitive stocks, or whether the various races have remained unchanged since they were created, the answer is perfectly definite and categorical. Whenever the evidence is sufficient as it is in this instance, it proves the theory to be a fact of record. When the evidence is insufficient for proof, it fits in with the evolution theory, so far as it goes. It is in comparatively few instances out of the millions of existing species that the categorical proof of their evolution is at hand. This will always be true, although the number of proofs and the completeness of the evidence grows year by year.

It is asserted by some opponents of evolution that "the

evidence is all circumstantial! " Probably what they mean is the anatomical evidence, which, moreover, they totally misconceive in saying that it is " a matter of resemblances." The fossil evidence, however, is not circumstantial; it is the direct testimony of the record itself, far better than " eye-witness testimony," for eye-witnesses may easily be mistaken, and often are, and there is no way to discover and correct their mistakes save the imperfect and uncertain methods of collation and cross-examination. As for the evidence of comparative anatomy, while it is indirect, and may be compared to circumstantial evidence, its weight lies not at all in " resemblances " but in identity of structural plan underlying a wide *diversity* of appearance and habits. We regard horse and man as related, not because they resemble each other, for they are utterly diverse in appearance, but because in spite of this diversity the anatomist finds that their underlying structure is fundamentally the same.[3]

The modifications involved in the evolution of the horse from primitive to present form may be briefly summarized as follows. First, there was a general increase in the size of the body from an organism of about twelve inches in height at the shoulders to one like the modern type which averages sixty-four inches in the same region of the body. Then again, the limbs became elongated and specialized for speedy movement. At first, when the ancestors were small, they were adapted to living in regions of brush or forest, and like many of the other small mammals of the time they were of the slow moving and browsing variety. Later on, as the air became dryer and the land more arid, the animals were modified and became grazing in type. This

[3] *Idem*, pp. 175–176.

change in habitat was responsible for exposing them more fully to view, thereby making it possible for enemies to spot them more readily. To protect themselves from being exterminated, they had to become larger and more powerful, and also speedier.

For the accomplishment of all this there must have been modifications in the entire body, particularly in the regions of the head, neck, and foot. The neck has grown consistently in length, to enable the animal to reach the ground without bending its knees. The head has become much larger, with the face greatly elongated, to allow room for the bigger types of teeth needed for grazing. The teeth themselves have undergone a remarkable transformation. In the early ancestors, which were browsing in habit, the teeth were all small and possessed short crowns with no cement or enamel crests. In the later forms, those which adapted themselves to grazing, the teeth became larger and developed elongated crowns which were supplied with cement and hard ridges, or crests, for grinding grass.

The changes which have taken place in the foot of the horse have been concerned with a general elongation of the bones and a reduction in the number of digits from five to one. The third digit, or middle toe, as it is called, is the one which has persisted, and its nail has become emphasized to such an extent that it has formed the hoof. Literally speaking, the foot of the horse has become so modified and specialized that the animal may be said to be walking, not only on tiptoe, but on its nails.

The fossil horses which have been discovered have

come mostly from America, and many competent authorities believe that this, in the main, is where the horse underwent its evolution. Remains of horses have also been found in Europe, but scientists are of the opinion that these migrated from America over a land bridge which at one time connected this continent to Asia in the region now occupied by Bering Strait. Dr. Frederick B. Loomis, in the aforesaid volume on the evolution of the horse, states definitely his belief that the horse originated in the northwestern portion of North America, and from there migrated to other portions of America, Asia, and Europe.

The complete evolution of the horse has been traced through about twelve stages, extending back to the early part of the Cenozoic era, when most of the mammals underwent their development. For our purpose, it will be necessary to mention only six of these in order to illustrate the essential steps in this evolution.

Eohippus. — This form lived during the early Eocene period, and measured between twelve and sixteen inches in height. The fore-foot possessed four complete toes and a vestige of the fifth one, whereas the hind-foot showed three distinct toes and a remnant of the first and fifth ones. The molars reveal short crowns with none of the crests found in the modern horse.

Orohippus. — This type existed during the middle of the Eocene period. It was slightly larger than the Eohippus, attaining the size of a small dog. In general make-up it resembled the Eohippus, bearing four toes on the front limbs and three on the hind ones. It differed from the Eohippus, however, in that the

remnant or splint of the fifth toe of the fore-limb had disappeared.

Mesohippus. — This form belonged to the Oligocene period, and attained the size of a sheep. The fore and hind limbs possessed three toes which touched the ground. However, the middle toe on each foot became specialized, growing larger and heavier than the other two, and undoubtedly it bore most of the weight of the body. The teeth were short-crowned structures, similar to those found in the preceding forms.

Merychippus. — This was the first grazing horse and developed in the Miocene period. It attained the size of a Shetland pony, was approximately forty inches in height, and possessed three toes on each foot, with the middle one emphasized over the others so that it was the only one that reached the ground. The two side toes were shorter structures which neither touched the ground nor bore any of the weight of the animal. The teeth became somewhat longer and corrugated. Lull calls this animal a transitional type, stating that

> the teeth are all short-crowned until Miocene time, when the grazing horses, with long-crowned teeth, appear in Merychippus as a response to climatic change. This creature possesses, moreover, short-crowned milk teeth, reminiscent of its ancestry, and long-crowned permanent ones, prophetic of the future. It is a truly transitional type.[4]

Pliohippus. — This, the first one-toed horse, made its appearance in the late Miocene and early Pliocene periods. The skeleton of the foot shows three distinct toes, the middle one, however, being large and

[4] *Ways of Life,* New York, Harper, 1925, p. 204.

well-developed, whereas the lateral ones are small splints that do not touch the ground. In general appearance, posture, and structure of teeth this animal resembled the modern horse, except in that it was smaller.

Equus. — This is the modern horse, and records of it are found first in the late Pliocene and early Pleistocene periods. The animal has become specialized to the extent that it walks entirely on a single toe, the third one. Furthermore, this third toe of each foot has become so modified that the nail has moved to its extreme end, and has been enlarged into the hoof. An examination of the skeleton of the foot shows that the first and fifth digits of the ancestral horse have been lost entirely, whereas the second and fourth ones have degenerated to the extent that they are represented by minute splints. The third one, on the other hand, has become over-emphasized to such a degree that it alone supports the weight of the body.

Figure 30, reprinted from Matthew's article, gives a diagrammatic presentation of the essential stages involved in the evolution of the horse. The only link which is missing and still remains to be discovered is the truly five-toed type which was ancestral not only to the horse, but also to other well-known mammals. Loomis believes that such a form possessed simpler teeth, shorter legs, and five toes on each foot. In discussing this question he remarks:

> There is a group of earlier Eocene forms in which we have these conditions, the *Condylarthra*, which seems to be a transitional group between horses, rhinoceroses, early carnivores, and primates. At times in the past *Phenacodus* has

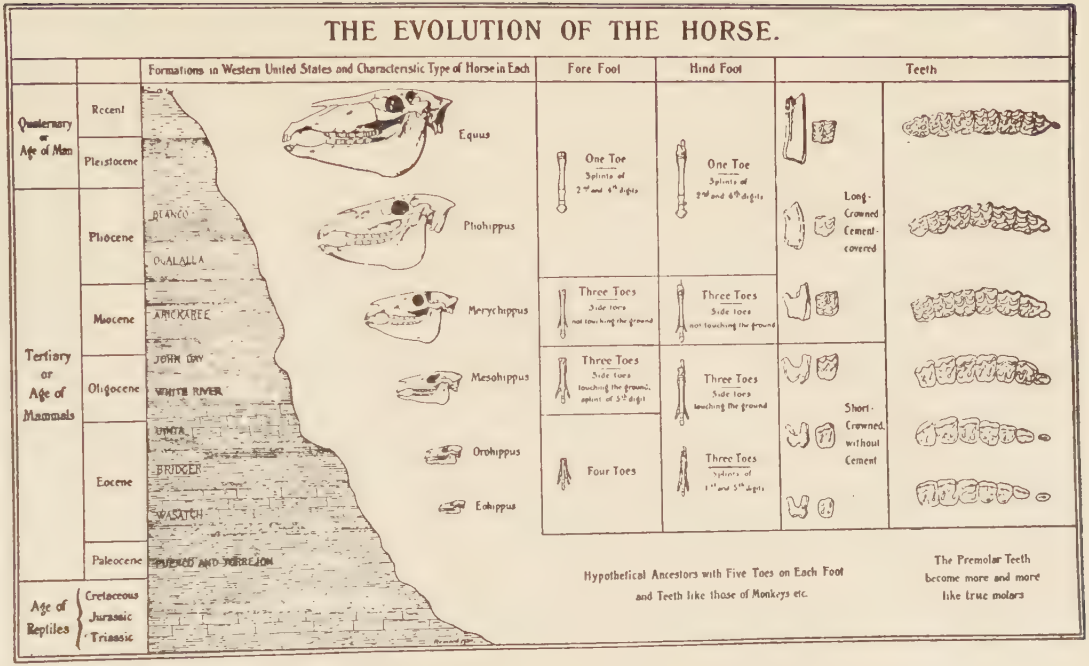


FIG. 30. THE EVOLUTION OF THE HORSE

(From Matthew, *Quarterly Review of Biology*, Vol. I. Courtesy of The Williams & Wilkins Co.)

been suggested as the ancestor of the horse, but it is a contemporary of the first horse, and is already specialized toward a heavier build and less active life. We cannot, then, consider this the ancestor, though it probably came from the same stock as the horse. There is a slenderer built form of this group, found in the basal Eocene or Torreon beds. It is *Tetraclænodon puercensis,* a small five-toed, light-built condylarth, which Broile believes to be the ancestor of the horse, but which Matthew thinks tends rather in the carnivore direction. These Torreon beds have yielded but few specimens, and it is possible that any day there may come from them a form which we can consider really ancestral. In any case, this *Tetraclænodon* differs but slightly from the requirements.[5]

3. Summary of Fossil Record

In closing the discussion of geological evidence, it may be well to summarize the facts which are revealed by a study of the fossil record of animal life. One of the first definite revelations of this record is that life on the earth has existed for a very long time, from at least the Cambrian period until the present day, covering a span of about five hundred million years. Most students believe that for about as many more years before the Cambrian period, during the Archeozoic and Paleozoic eras, there must have been life in the form of very simple organisms; but, owing to the fact that these did not contain any hard parts, exceedingly few of the types have been preserved. Therefore, it is safe to estimate that during the last billion or more years living matter has actually existed upon the earth.

[5] *Op. cit.,* pp. 76–77.

The second big revelation of the geological time record is that organisms have evolved from simple and undifferentiated to complex and differentiated forms. The evidence is clear-cut on this point. Records of the simplest animals have been found in the oldest formations, the more complex organisms in the later ones, and the most highly organized forms, including man, in the most recent layers.

The third and last fact disclosed by the geological record is that man has undergone an evolution similar to that of other animals, but that he required a longer time to reach his high degree of mental complexity. No human remains ever have been discovered in the strata which were deposited prior to a few million years ago. They appear for the first time in the layers of the latter portion of the Cenozoic era, and more particularly in the Pleistocene period of the Psychozoic era. Because of this fact, man must be regarded as the most recent product of animal evolution; and, consequently, it has taken nature the longest interval of time to evolve him to his present level of attainment. The fact must be emphasized, however, that man, by innumerable ties, is closely linked to the lower animals, showing similarities which indicate not only his identity but also his ancestry.

4. Geographical Distribution

Life not only has been of wide distribution in past generations, but at the present time it is profusely dispersed over the entire globe. There is hardly a region that does not boast of a rich and varied group of animals

and plants. Even in the case of localities quite similar with respect to climatic conditions the organisms which dwell in them often are found to differ markedly. Our present knowledge concerning the history of life upon the earth indicates that definite types of organisms became established in definite areas and predominated to such an extent that these areas soon became centers of population for the forms in question. In the course of time the individuals multiplied and many of them began to migrate to such neighboring regions as became accessible to them. At first, while environmental conditions were still favorable, this migration from the central base doubtless took place slowly; but as the types became more numerous and the struggle for existence keener, it became more rapid, so that the adjacent sections soon became inhabited with similar forms.

This dispersion was caused by many factors, and was accomplished in numerous ways. Sometimes land bridges connecting large masses of the earth's surface were responsible for it; at other times ærial flight, gusts of wind, currents of water and air, played an important *rôle*. Organisms that dwelt in water and were able to swim long distances came to populate localities far removed from their central base. Many types were doubtless transferred to distant places accidentally on such objects as floating logs, ice floes, floating masses of vegetation, and even on bodies of land that happened to break away from shores. These same factors are operating at the present time to effect the dispersion of many forms of animals and plants.

Whether the causes of the migration of organisms

were accidental or natural, they have been entirely adequate to cover this planet with a great wealth of animal and plant life. Furthermore, this migration has been largely responsible for the diversity of living forms to be found in nature. It must not be forgotten that the surface of the earth has been undergoing various changes, many of them very extensive. Many types, after migration, encountered new conditions in which it was necessary for them to orient themselves. Those unable adequately to do this either remained few in number or became extinct, thus leaving the region to the forms that could adapt themselves to the changed circumstances; and these forms, in turn, soon became so modified that they were distinctly marked off from their ancestors. Moreover, each of these new types became a nucleus for new migrations and new variations.

Another factor which must be stressed in discussing geographical distribution is this: after organisms moved from their original centers, the changes which took place upon the earth often set up definite barriers between the forms that still inhabited the central location and those which populated the new regions. Such barriers inevitably brought about isolation, so that in the course of time the organisms thus cut off evolved and produced types that differed markedly from the primordial stock.

The factors tending to bring about isolation by acting as barriers to the dispersion of organisms have been numerous and diverse. Those which have operated in past generations, and are still operating, will be briefly indicated. Often dense forests, mountain ranges,

deserts, glaciers, and regions of volcanic activity prevented organisms from penetrating into neighboring localities. Salt water usually has acted as an efficient obstacle to the migrations of fresh-water forms, and vice versa. Occasionally, bodies of water or land were the barriers, the former checking the dispersion of exclusively land-dwelling types, the latter presenting a similar problem to purely aquatic forms.

Very little variation is found among organisms capable of traveling great distances back and forth over difficult areas which ordinarily serve as barriers. On the other hand, species that do not have the means of locomotion that enable them to overcome such obstacles find themselves isolated and in time are so transformed and modified that they become distinct species, showing differences which set them off definitely from the parent stock. Darwin, Wallace, Romanes, Beebe, and others have brought to light a large number of such facts, particularly through their comparative studies of the fauna and flora of islands and of the mainlands closest to them.

Students of geographical distribution have shown that two kinds of islands exist; namely, continental and oceanic. Both kinds have been studied and the resulting discoveries have afforded splendid proof of the evolution of species. The continental islands are those which show the same geologic formation as the mainland of which they were once a part and from which, through certain circumstances, they have been cut off. Oceanic islands, on the other hand, are wholly of volcanic origin and in many instances show little resem-

blance to the closest mainlands. Some scientists believe that oceanic islands arose as distinct entities from the bottom of the sea, and have never been connected with the larger masses of the nearby continents. Others discredit such a theory and believe that these islands, although they now appear as separate regions far distant from neighboring shores, nevertheless were once connected with them by distinct land bridges.

From a historical standpoint, the oceanic islands have been of greatest significance to students of evolution. The Galapagos Islands, in particular, have proven of great interest to those who have dealt with problems of the distribution of organisms, and have revealed many facts to substantiate the evolutionary conception. These islands, about sixty in number, are grouped into what is known as the Galapagos Archipelago, situated in the equatorial belt some six hundred miles west of Ecuador. All of them volcanic structures, they were first discovered in 1535 by the Bishop of Panama, who gave the archipelago its name because of the giant tortoises which he found existing there. In 1835, just three hundred years after its discovery by the Spanish, Charles Darwin, while cruising around the world as a naturalist on His Majesty's ship, the *Beagle*, in search of scientific data, visited the archipelago and spent five weeks in studying the fauna and flora of its larger islands. It might be said that what Darwin saw in the Galapagos Archipelago afforded, to a large extent, the basis for his views on evolution. He found that each island possessed its distinctive organisms, and that these, while they had their counterparts in other islands

as well as on the nearest mainland, nevertheless were varied to the extent of being classifiable as definite varieties or species. Without doubt they showed the effects produced by isolation in a particular locality.

Concerning the natural history of the islands Darwin says:

> Most of the organic productions are aboriginal creations, found nowhere else; there is even a difference between the inhabitants of the different islands; yet all show a marked relationship with those of America, though separated from that continent by an open space of ocean, between five hundred and six hundred miles in width. The archipelago is a little world within itself, or rather, a satellite attached to America, whence it has derived a few stray colonists, and has received the general character of its indigenous productions. Considering the small size of these islands, we feel the more astonished at the number of their aboriginal beings, and at their confined range. Seeing every height crowned with its crater, and the boundaries of most of the lava-streams still distinct, we are led to believe that within a period, geologically recent, the unbroken ocean was here spread out. Hence, both in space and time, we seem to be brought somewhat near to that great fact — the mystery of mysteries — the first appearance of new beings on this earth.[6]

In 1923 William Beebe, the American naturalist, headed an expedition to the Galapagos Archipelago and obtained results of far-reaching importance, from the standpoint of evolution, with reference to the effects of

[6] Darwin, Charles, *Journal of Researches into the Natural History and Geology of the Countries Visited During the Voyage of H. M. S. Beagle*, London, John Murray, 1852, pp. 377–378.

geographical distribution and isolation on organisms. Beebe spent only about one hundred actual hours in the archipelago, concentrating attention on the life of the smaller islands and islets. He has published a large volume entitled *Galapagos: World's End*,[7] in which, in a truly fascinating manner, he describes the results and accomplishments of the expedition. In spite of the fact that they spent little time in the archipelago, the scientists connected with the expedition collected a wealth of animal and plant species. These have been studied by numerous specialists, and many of the results have been published in a number of separate monographs. There have been other expeditions to these islands, but all have gathered similar data and arrived at conclusions much the same as those of Darwin and Beebe. A few illustrations will suffice to indicate the scope of some of these deductions.

It was found that the giant land tortoises, after which the archipelago is named, were of different types on the individual islands, and that each island really possessed its own kind. Darwin's observations led him to this conclusion, and since his time it has been definitely confirmed by other scientists, particularly those of the expedition sent in 1905–1906 by the California Academy of Sciences. Van Denburgh, the reptile specialist of the California Academy of Sciences, has classified fifteen races or species of tortoises from the archipelago. Ten of these came from ten different islands, one on each of them, whereas the remaining five were found on the largest island, Albermarle, where differentiation

[7] New York, Putnam, 1924.

had progressed to the extent that five distinct kinds were found to inhabit five different portions of the island.

It is interesting to note that tortoises similar to those living in the archipelago have been discovered in the region of Colombia, South America, and also in the Panama area of Central America. These forms do not attain the giant size of those in the Galapagos Islands. Beebe, in trying to trace the evolution of the Galapageian tortoises, mentions the important fact that fossils of giant tortoises, similar to those under consideration, have been unearthed in Cuba. Inasmuch as most investigators, with the exception of Beebe, are of the opinion that the land tortoises cannot swim great distances, the question of their arrival in the archipelago is one of tremendous significance. Beebe and other students believe that at one time all of the territory included in the vicinity of Central America was connected by a land bridge with the Galapagos Islands. At first there were no separate islands, but huge volcanic peaks were joined to one another by dry land and formed a single area continuous with the bridge that stretched from Central America. The animal and plant life which existed in the latter locality also must have extended to the outer regions of the volcanic formations.

All this occurred long before the higher mammals, including man, made their appearance upon the earth. Through the agencies of subsidence and of volcanic eruptions, the land bridge sank into the Pacific Ocean, leaving the towering volcanic peaks exposed to view, and these formed the islands which now compose the

archipelago. The connection with the mainland thus was destroyed, and a water channel, six hundred miles wide and between two and three thousand fathoms deep, was produced. Many organisms undoubtedly were cut off and isolated in this manner; after many years of adaptation and adjustment they evolved into new types and species.

Those forms which could migrate back and forth over the segregated islands, and also to the mainland, show the least modification, as is confirmed by some of the birds and particularly by the species of large sea-lizard which dwells on the shores of the islands or in the waters between them. There is just one type of such lizard, about four feet in length, that is able to swim from island to island, crossing freely with forms that have inhabited particular localities, and thereby effacing individual variations from type. A relative of the giant marine lizard has been found inhabiting the land of the islands in the center of the archipelago. This form resembles the sea species in general size and weight, but differs from it in color and habits, as also in certain structural details. Those who have carefully studied both the sea and the land lizards believe that they not only are closely related to each other, but undoubtedly have been derived from a common ancestor similar to the iguanas of South America. One branch adapted itself to a marine existence, the other to land life. These giant reptiles must not be confused with the small *Tropidurus* lizard which abounds on the islands. Beebe and others have described seven species of this tiny form, all exclusively terrestrial in habitat.

The insects, fishes, crustacea, birds, and other animals, although they show a general resemblance to those of the mainland, particularly the region of Central America, nevertheless have become modified distinctly into new forms as the result of isolation and adjustment to the peculiar environmental conditions of the islands. Botanists who have studied the flora of the archipelago have pointed out similar facts, indicating quite conclusively that not only the animals but also the plants have been influenced by the same natural factors which were responsible for the emergence of the organisms in the archipelago. In the last chapter of his book on the Galapagos, Beebe considers the origin of this important archipelago. After a critical examination of the various theories promulgated to account for the existence of the islands, he presents facts to substantiate his conviction that the islands were at one time continuous dry land and also that a land bridge formerly connected them with the mainland of Central America. He thereby takes exception to Darwin's view that the islands never were connected with one another and, furthermore, that they never were joined to any continental mass.

In this connection it must be repeated that the study of the past and present history of the earth has convinced scientists that tremendous changes have taken place upon it; certain regions now separated by wide ocean areas at one time were connected by definite land bridges; and the organisms which were common to one wandered, unhampered, to the other. Dr. Metcalf,[8] in

[8] *Lectures upon Evolution and Animal Distribution*, University of Buffalo Studies, vol. 2 (1923), no. 4, pp. 152–183.

an interesting lecture on " Animal Distribution and Ancient Distribution Routes," given before the University of Buffalo, presented a series of extremely illuminating maps, showing the manner in which lands appeared during successive periods of geologic time. A few of these reprinted here, Figure 31, show many of the probable land connections which have been responsible for the dispersion of organisms to the areas in which they now dwell.

Prior to the promulgation of the evolutionary hypothesis, the facts revealed by the study of the geographical distribution of organisms were looked upon as hopelessly confusing. Believers in the doctrine of special creation could not explain them, because, as has been mentioned, often localities which were absolutely alike with respect to climatic, land, and water characteristics were found to possess radically different organisms. Similar types were distributed, not in areas with similar features, but in those which were closest to the centers in which the types originated. According to the special creationists' point of view, like species should exist in those places where climatic and other environmental factors are more or less the same; but this, as is well known to all students of animal and plant life, is not the case.

The evolutionary explanation has led scientists out of this dilemma and has clarified this seemingly hopeless confusion. Two evolutionary points of view have been postulated to account for the dissemination of organisms over the earth. The first is that which has here been elaborated, namely, that living types originated in

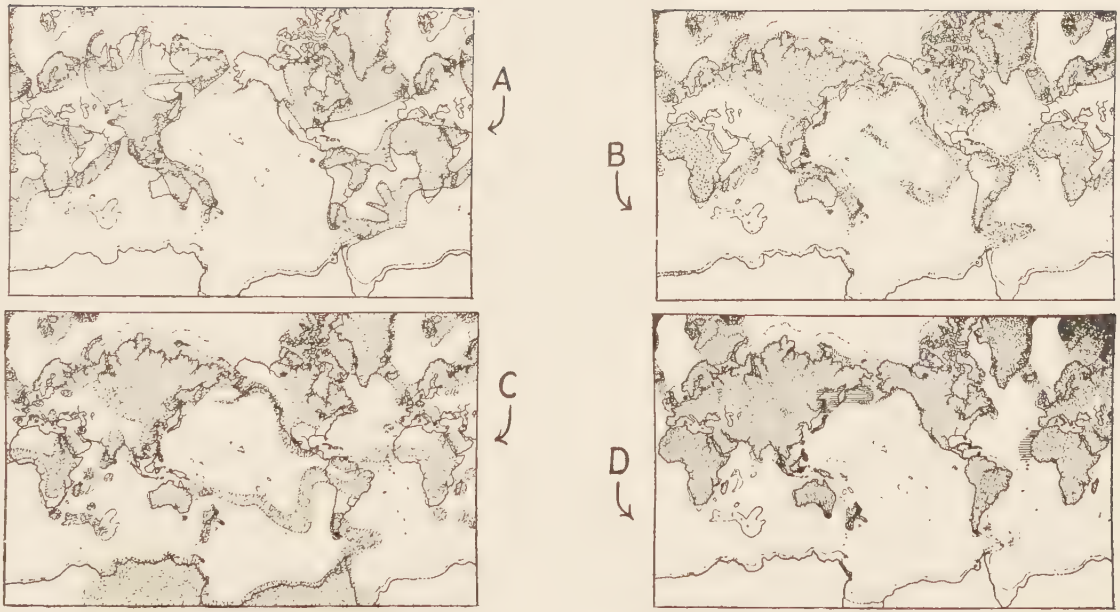


FIG. 31. THE APPEARANCE OF CONTINENTS IN PAST GEOLOGIC AGES

A, jurassic continents; B, early cretaceous continents; C, late cretaceous continents; D, late tertiary continents. The stippled or lined areas represent land formations. (From Metcalf, "Animal Distribution and Ancient Distribution Routes," *Univ. of Buffalo Studies*, Vol. II. Courtesy of the University of Buffalo.)

central localities, only one type in a specific area, and that these types, through the agencies of migrations and barrier isolations, gave rise to new forms. It must not be inferred from this discussion that each area had just one kind of organism and no other. The idea which it is desired to convey is that types had their beginnings in definite locations and from these radiated out to neighboring locations. At the same time the migratory factors responsible for the dissemination also brought in numerous other organisms, and in these areas they underwent an evolution concurrent with that undergone by the types already common to the locality.

The other point of view is that known as "parallel evolution," which holds that similar forms originated in distant places, either at the same or at different periods of time, and there underwent a parallel evolution. This view, while it may serve to explain the evolution of the same types, does not explain certain facts disclosed in recent years, particularly in regard to the parasites which infest these similar organisms which act as their hosts. Parasitologists have shown that the hosts, although separated by great distances, are alike not only in regard to structure and behavior, but also in regard to the parasites which infest them. Whereas one may understand that the same hosts undergo a parallel evolution in widely divergent localities, it is hardly to be expected that the parasites which infest them should not only be identical, but should also reveal a similar evolution. Salient facts such as these have led most students to reject the conception of parallel evolution and to accept the one already considered in this chapter.

In recent years biologists have stressed geographical distribution and isolation as having great value in the development of the present fauna and flora. Numerous investigators have concentrated their attention on this subject and have produced conclusive evidences that species have been formed in the manner indicated. Some students also have pointed out that where the full history of a species has been traced over a large geographical area showing regions of climatic differentiation, then not only distinct sub-species have developed, but also intergrades, connecting links between sub-species, especially in those localities that mark the termination of one zone and the beginning of the next. Moreover, it has been pointed out that, were it not for the intergrades, the sub-species would certainly be classified as absolutely distinct species, because they show such marked divergencies from the common type.

Grinnell says in regard to this subject:

> Lest there be misunderstanding on this point, let me explain that sub-species and species are identical things, phylogenetically; they differ only in the circumstance that related sub-species intergrade spatially: some feature of surface geography or in the history of their differentiation has allowed continuous free intercourse between the two differentiating populations, so that intermediates persist. Between any two " full " species there is an absolute gap or hiatus. . . . Observation of species in the wild convinces me that the existence and persistence of species is vitally bound up with environments. The extent and the persistence of a given kind of environment bear intimately upon the fate of the species we find occupying that environment. Environments

are forever changing — slowly in units of recent time, perhaps.[9]

In dealing with the geographical distribution of organisms and species, one must constantly keep in mind what already has been emphasized regarding the time element necessary for the origin and occurrence of variations, even very slight ones. Time must be calculated, not in terms of a few years, but in thousands or perhaps millions of years. When action, interaction, and adaptation between living forms and the environment have occurred over such long periods of time as the evolutionist has in mind, then changes in type become a possibility. Again we may quote Grinnell:

> Note that I, as a systematist, insist that the element of *time* has been involved in the formation of species and subspecies, as I know them in the wild. I have never found evidence that would lead me to suppose that any of the existing kinds of mammals or birds in western America came into being suddenly. There is much good evidence to show that *slow* lapse of time has accompanied all differentiation.[10]

Professor H. F. Osborn enumerates the groups of organisms in which research has established definitely the fact that species have originated and are still in the process of formation through the factors of geographical distribution, especially through isolation.[11] He also enumerates specific results obtained in molluscs, fishes,

[9] "Geography and Evolution," *Ecology*, vol. 5 (1924), pp. 225–229.

[10] *Ibid.*

[11] "The Origin of Species. V: Speciation and Mutation," *The American Naturalist*, vol. 61 (1927), pp. 5–42.

amphibians, reptiles, birds, and mammals. In discussing the mammals, he mentions the work of the American investigators, Osgood and Sumner, particularly that of the latter, on the distribution of deer-mice or prairie mice of the genus Peromyscus as the most convincing demonstration of speciation (the making of species) continuity which has thus far been produced.

In a preceding paper, which Dr. Osborn read at the Oxford meeting of the British Association for the Advancement of Science, he summarizes the work on Peromyscus as follows:

> Far more significant, however, are the observations of Osgood and Sumner on the deer-mice of the genus Peromyscus, which range through the temperate region of North America to the Pacific coast. From a collection of 30,000 specimens Osgood finds that a sub-species is characteristic of every distinct climatic region and sub-region. These sub-species listed by Merriam and Osgood have been accepted with great reluctance, especially by naturalists unfamiliar with the excessively sharp geographic and climatic barriers of the western United States. Our hesitation to accept these sub-species as of real germinal or genetic value has been entirely removed by the persistent observations and experiments of the biologist Sumner, largely in the identical collecting grounds of Osgood, and we must welcome these combined observations and experiments as the most convincing demonstration of the principle of speciation continuity thus far afforded. Between at least six of these sub-species complete intergradations occur. Classification becomes like dividing the lines of the spectrum. After eight years of transfer from an arid to a humid environment, or vice versa, these sub-species retain their original characters. Even profound

change of environment does not yield a new sub-specific form, nor are changes of habit inherited in eight years of experiment.[12]

In the first-mentioned paper by Osborn occurs the following excellent statement summarizing the discussion of species formation through the agency of geographical isolation:

It appears that the problem of the age-long process of the origin of species can best be studied under the natural conditions of past and present times; it appears that all vertebrates which range into a new set of natural conditions, whether by geographic isolation or otherwise, in the course of time give rise to new specific forms; it appears that, where vertebrates can be traced from one geographic range as it merges into another, "transitional" or "intermediate" forms are observed, so that if placed side by side, one subspecies passes gradually into another by intergrades, and thus the supposed barriers existing between species and subspecies disappear.[13]

Finally, Grinnell, one of the ablest investigators in the field of animal distribution, is of the firm conviction that organic evolution has proceeded in somewhat the following manner:

Stocks have been isolated under peculiar and differing sets of conditions. Differentiation of these stocks has ensued; invasion has come about, because of the centrifugal

[12] "The Problem of the Origin of Species as it Appeared to Darwin in 1859 and as it Appears to us Today," *Science,* vol. 64, N.S. (1926), pp. 337–341.

[13] "The Origin of Species. V: Speciation and Mutation," *The American Naturalist,* vol. 61 (1927), pp. 5–42.

pressure of growing populations; migration of the young races has taken place by reason of the movement of the boundaries of geographic units, in other words, of barriers; and the subsequent re-invasion, by the further differentiated stocks, of areas inhabited by the ancestors has taken place. This process, of *evolution,* has involved time and space concurrently. . . . The factors which have caused and directed organic evolution, and which continue to do so, are bound up in the evolution of environments. It is immaterial just how variations arise. Evolution has not begun until trial begins. Since, therefore, organic evolution is the result of the interaction of organic life and diversifying environments, a study of geographical distribution and adaptation is, in at least the vertebrate animals, necessary to an understanding of the causes and methods of evolution.[14]

[14] *Loc. cit.*

CHAPTER VIII

EVIDENCE FROM MORPHOLOGY

The evidences for evolution from the field of morphology are concerned with the fundamental form, structure, and organization of the various types of animals and plants. In spite of the fact that organisms appear to differ externally, many of their organ systems show so many striking resemblances internally that the scientific world long ago reached the conclusion that this must have some significance from the standpoint of origin. Just as a master mason can construct a variety of edifices with the essential materials which form the average building, so nature has constructed different organisms from the same general components which enter the make-up of living matter. The more the biologist studies living creatures, the more is he impressed with the evidences revealed by morphology and the stronger is he convinced that they bear out the evolutionary interpretation of the development of living matter in its various forms. These evidences will be discussed under the headings of comparative anatomy and serology.

1. Comparative Anatomy

Comparative anatomy deals with the structure of organisms in a comparative way, and attempts to

uncover these similarities as well as modifications which reveal existing relationships. In comparative anatomy, although the external form of organisms is important, the internal organization is even more so. This latter phase of morphology brings out certain identities of make-up dependent on similarity of origin, and are technically known as homologies. The structures showing these salient resemblances are called homologous structures, and are considered of most importance in the present system of classifying organisms, namely, the natural system of classification. This scheme of grouping animals and plants is based mainly on their degree of complexity which, at the same time, reveals their evolutionary sequence.

The first doctrine of comparative anatomy is that fundamentally all organisms are composed of the same unit of structure, the cell (Figure 32). The cell is regarded as the basis of organization for the lower as well as the higher forms of life. Essentially all cells contain the same parts — nucleus, cytoplasm, and centrosome, — each functioning in a somewhat similar fashion in different organisms.

Another fact which can be discovered from a study of the comparative anatomy of organisms is that similar tissues in different animals are somewhat similarly constructed, whether they be found in a highly complex organism or in one that is lower down in the scale of evolution. Take, for instance, voluntary muscles in the invertebrates and vertebrates. Any student familiar with these tissues knows that the same essential components enter into their make-up; this is also true of

connective, nervous, and various other tissues which form the united whole of the multi-cellular organism. The inference must not be drawn that these tissues are as highly complex in the lower animals as in the more advanced, or that all are represented; but it remains true that fundamentally the same scheme of organization runs through *all* tissues having the same character.

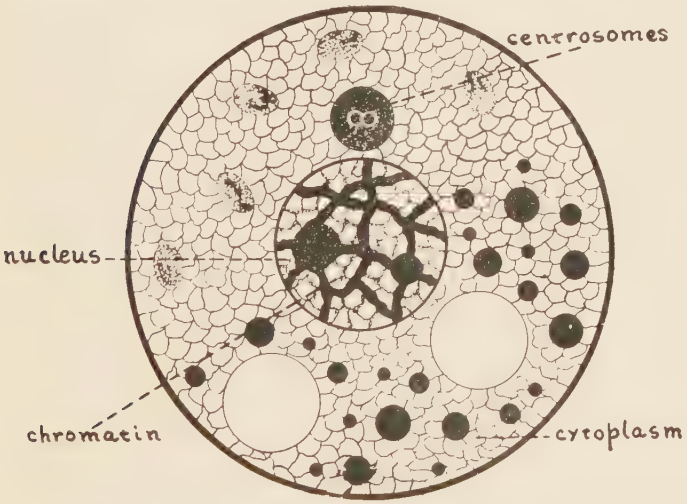


Fig. 32. Structure of a Typical Cell

Comparative anatomy also reveals that the principal organ systems of animals show considerable similarity, and in many instances are homologous, possessing not only the same internal organization, but also the same origin from the standpoint of development. The vertebrates afford, in singular fashion, some of the best instances of such resemblances. All of them are built on a similar plan, possessing bilateral symmetry and paired

appendages. Externally many of the appendages appear to be distinctly different, having been specialized for definite purposes, such as flying, swimming, running, jumping, or grasping. Internally, however, they are constructed similarly, that is, they are homologous. For instance, when such structures as the wing of the

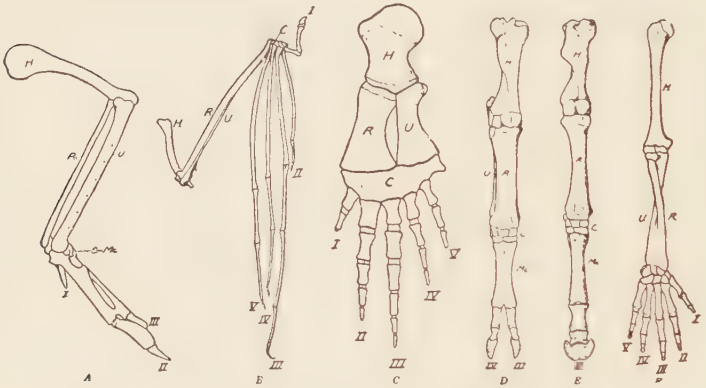


FIG. 33. HOMOLOGOUS STRUCTURES

A, left wing of a bird; B, right wing of a bat; C, left flipper of a whale; D, right fore-leg of an ox; E, right fore-leg of a horse; F, right arm of a man; *C,* carpals; *H,* humerus; *Mc,* metacarpals; *R,* radius; *U,* ulna; *I-V,* digits. (From Newman, *Outlines of General Zoölogy,* after Scott. Copyright 1924 by The Macmillan Co. Reproduced by permission.)

bird, the wing of the bat, the flipper of the whale, the fore-limbs of hoofed mammals, and the arm of man are compared externally, they seem to be distinctly different so far as organization is concerned; however, an internal examination soon reveals that all are identical appendages and possess similar components (Figure 33). All of the various organ systems of the ver-

tebrates, when studied comparatively, show so many homologies as to afford a convincing proof of relationship which lends itself to but one interpretation, that of identity of origin.

In dealing with evidences from comparative anatomy, the so-called rudimentary structures, or those which have lost their function and appear to be useless in organisms, must be mentioned. Rudimentary structures afford some of the strongest evidence for evolution. They are found in all animals and plants, particularly the higher ones, and undoubtedly they have served some purpose during a certain period in the history of the forms in question. When these species had to adapt themselves to a changed environment, the functional uses of many of their parts often were so radically interfered with that modification and atrophy took place, and degeneration resulted.

Good examples of rudimentary structures are found where the animals have adapted themselves to special habitats or to peculiar environmental conditions. Organisms such as crustacea, fishes, and salamanders, which have become accustomed to darkness, have gradually lost the power to see because they have had no use for this faculty in their environment. Going hand in hand with such adjustment, the eyes atrophied until they became mere vestiges. The interesting observation here is that where similar kinds of animals dwell in localities in which vision is necessary, the organs of sight are highly specialized and fully developed for receiving light stimuli. In either case, the environment conditions the expression of the structure in question;

where eyes are necessary, they become highly specialized for functioning; where they are not needed, as in caves, they degenerate and in many instances entirely disappear. In the ground mole we see a similar condition, the animal living in underground burrows away from the light. Here injury to the eye may also have played a part in hastening its atrophy.

Some birds that dwell in regions which afford them protection from enemies, or where enemies are entirely lacking, have lost the use of their wings for flying. Since flight became unnecessary as a means of escape, the wings fell into disuse and gradually dwindled away until at the present time they appear as mere remnants of their former selves. One of the existing birds which illustrates this interesting feature is the *Apteryx* of Australia (Figure 34), the wings of which have been so reduced that they are small stub-like structures, entirely covered by the external feathers.

The rudimentary structures most interesting to us as human beings are those found in our own bodies. The anatomist, Wiedersheim,[1] enumerates between one hundred and fifty and two hundred such features, pointing out that these were undoubtedly significant at some time during the evolution of the human species; owing to changing conditions of his environment, however, man has had to make so many adjustments that numerous portions of his body have become useless, having atrophied to such an extent that they are now mere relics. Dorsey, in his volume entitled *Why We Behave Like Human Beings*, says:

[1] *The Structure of Man*, New York, Macmillan, 1895.

What does it all mean, this astounding range of variation, on which I have barely touched? There they are, by the thousands, by unnumbered thousands. Shall we say that they lie. . . . Or shall we say that we are walking museums of comparative anatomy and try to find out whence we came and whither we are going? This is certain: there is no fixed,

FIG. 34. APTERYX AUSTRALIS IN NATURAL SURROUNDINGS

The external wing is to be seen in the upper right-hand corner. (From Romanes, *Darwin, and After Darwin.* Courtesy of The Open Court Publ. Co.)

standardized, perfect, or biologically ideal human body; there are no two human bodies quite alike. Each one of us reeks with evidence that our ancestors were not the two-handed, two-footed creatures we are now; that they had no talking muscles; that they could not back up their talk with

a speaking countenance; and that they could not balance their heads on their spines.[2]

Occasionally one sees a person who can wiggle his ears or move the top of his scalp. In the vast majority of people the power of moving these portions of the head has been lost completely, because the muscles which control this movement have degenerated to such an extent that they have lost their functions. However, practically everyone is capable of wrinkling the forehead and contracting the eyebrows, because in these places the muscles under the skin still retain their functions. In a large number of mammals many parts of the outside skin are capable of independent movement, so that the organisms are able to respond more efficiently to stimuli which affect them. In some of the higher apes and in man this power has been lost in most portions of the skin, but still continues in the regions of the head and neck. So far as the human species is concerned, vigorous motion is still possible in the forehead and, to a very much lesser degree, in the regions of the ear and scalp.

The human eye shows an interesting rudimentary structure in the form of a thin fold of skin situated in its inner corner near the tear gland. Ordinarily this is called the third eyelid, but technically it is known as the *plica semilunaris*, or the nictitating membrane. Figure 35 shows how it is expressed in the eyes of different organisms. In many vertebrates this structure is fully developed, appearing as a semi-transparent lid which can be moved rapidly across the eye for purposes of

[2] New York, Harper, 1925, p. 31.

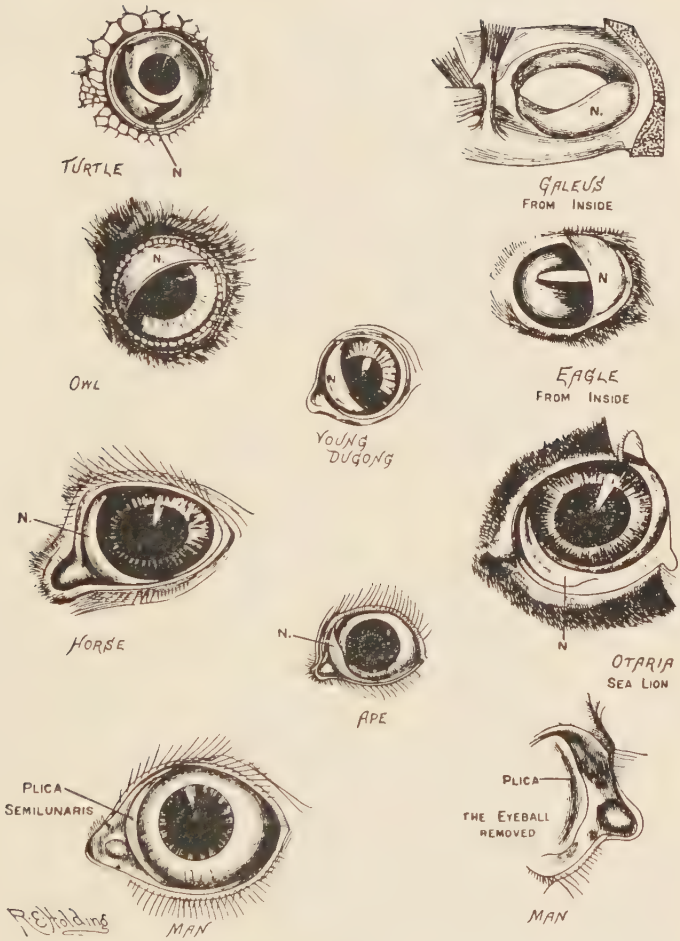


FIG. 35. THIRD EYELIDS IN VARIOUS ANIMALS

Also called nictitating membranes, or *plica semilunaris*. N indicates the third eyelid. (From Romanes, *Darwin, and After Darwin*. Courtesy of The Open Court Publ. Co.)

cleansing or protection when there is danger of injury. In amphibians, reptiles, and birds it is particularly well developed. It is more prominent in some mammals than in others, whereas in man it has fallen into disuse and may now be recognized only as a rudiment.

The hair on the outside of the body also may be classified in the category of rudimentary structures. Nearly all mammals have a heavy growth of hair on all parts of the outer skin. Man, on the other hand, has hair on only a few confined regions of the body, whereas on most of the skin it is but slightly developed. When one studies the direction in which the hair grows, particularly on the outer surfaces of the hands, arms, and legs, one observes that it is similar to that found in the apes (Figure 36). This not only affords strong evidence of kinship, but also bears witness to evolution of human beings and apes from a common, lower type of mammal.

Another rudimentary structure in apes as well as in man is the tail. Virtually all mammals possess such an appendage, which, when examined, is found to be an extremely muscular structure, with numerous small bones, which are really distinct parts of the spinal column, known as the caudal vertebræ. In most of the apes the tail has become reduced until it consists of a few of these vertebræ (Figure 37) and may be distinguished externally as a small projection. In man, this structure cannot be seen from the outside, except in a few rare instances, where it has been known to be developed (Figure 38). Internally, however, the posterior

FIG. 36. HAIR TRACTS ON ARMS AND HANDS OF MAN AND CHIMPANZEE

(From Romanes, *Darwin, and After Darwin*. Courtesy of The Open Court Publ. Co.)

portion of the backbone reveals four or five small bones called, collectively, the coccyx, which in early life are separate but later become fused into one structure. In this connection it is of interest to mention that in the

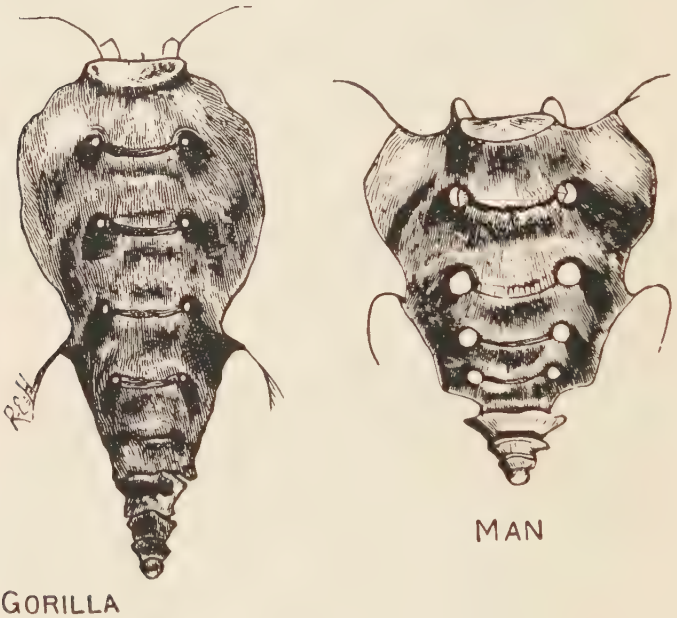
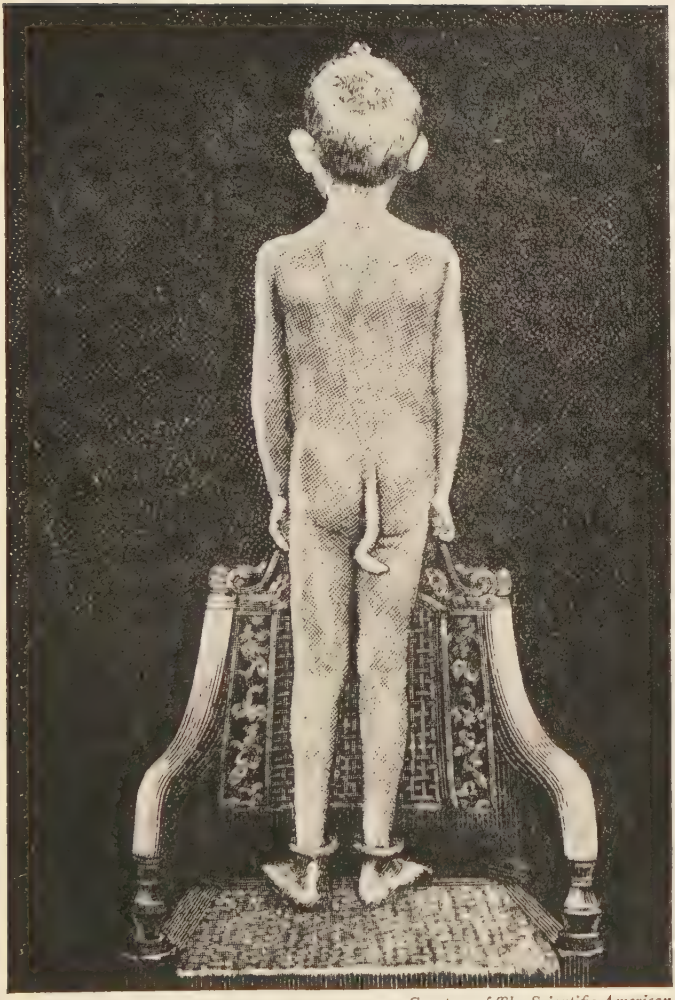


FIG. 37. RUDIMENTARY TAIL BONES IN GORILLA AND MAN

(From Romanes, *Darwin, and After Darwin*. Courtesy of The Open Court Publ. Co.)

embryonic development of man a distinctly prominent tail is present, and it is supplied with muscles that enable it to undergo independent motion; but as development proceeds, atrophy occurs and the tail as well as the muscles degenerate.



Courtesy of The Scientific American

FIG. 38. YOUNG BOY WITH A VISIBLE TAIL

In a very young child there are certain features of posture and structure which might be considered rudimentary, and which indicate clearly the relationship of human beings to the apes and other mammals. The hands have strong powers of grasping, out of all proportion to the needs of the child. The general bend of the legs is such that they remind one of a monkey's limbs, curving in such a way as to give the impression that they could very easily entwine themselves around an object for support. The feet in particular have an ape-like appearance, the soles facing one another and the large toes separated from the rest by a wide gap. Needless to say, this last-named feature is of benefit to the apes in securing a foothold when climbing or progressing over rough territory. When a very young infant is allowed to hang by its hands, its body assumes a position reminiscent of a small monkey in the act of attaching itself to the trunk of its mother, in order to hang on while she is moving from place to place. This posture of the limbs has persisted to a marked degree in the small baby (Figure 39), but is lost as soon as the child develops to the stage where it begins to utilize its independent faculties.

The rudimentary structure perhaps best known to the average person is the vermiform appendix (Figure 40). It is located internally in the abdomen, in the region where the large intestine branches off from the small one. In man it is an entirely useless structure, becoming infected and inflamed under certain conditions and often endangering life. In animals whose diet consists of vegetation — herbivorous animals — the ap-

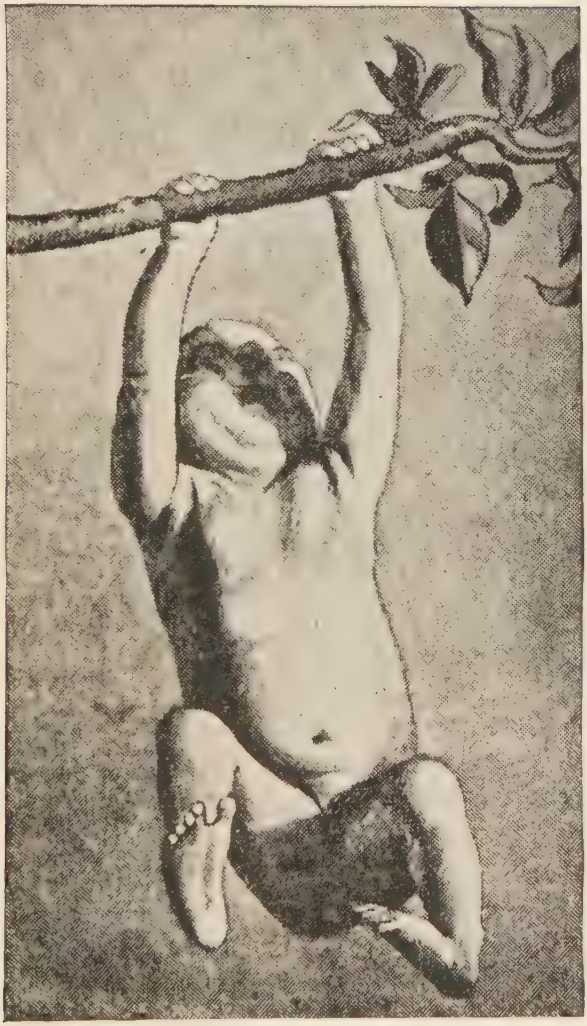


FIG. 39. HANGING POSITION OF AN INFANT

(From Romanes, *Darwin, and After Darwin.* Courtesy of The Open Court Publ. Co.)

pendix is quite elongated and functions as a definite portion of the intestinal tract. On the other hand, in carnivorous animals, which are flesh-eating, there is not the need for such a long intestine, so that the appendix has dwindled until it has become a mere vestige of its original self. Biologists who have studied the question assume that man, in his evolution, has changed from a diet which was mainly herbivorous to one which was more carnivorous, and that during this transition a portion of the intestine in the region where the vermiform appendix is located degenerated until it became the small structure that it now is.

Many other rudimentary structures can be mentioned, and all of them may be interpreted in the manner indicated; that is, they are the relics which disclose relationship, change, and evolution. Ernst Haeckel says of rudimentary structures:

> They are among the most important evidences for the truth of the mechanical theory of nature, and among the most overwhelming proofs against the prevailing teleological ideas of creation. If, in accordance with this latter view, Man and every other organism had been designed for his life-purpose from the beginning, and had been called into existence by an act of creation, the existence of these rudimentary organs would be an incomprehensible enigma; it would be impossible to understand why the Creator should have laid this useless burden on his creatures in their life-journey, so arduous at the best. On the other hand, by means of the Theory of Descent, we can explain their existence in the most simple way, and say: The rudimentary organs are parts of the body, which, in the course of centuries, have

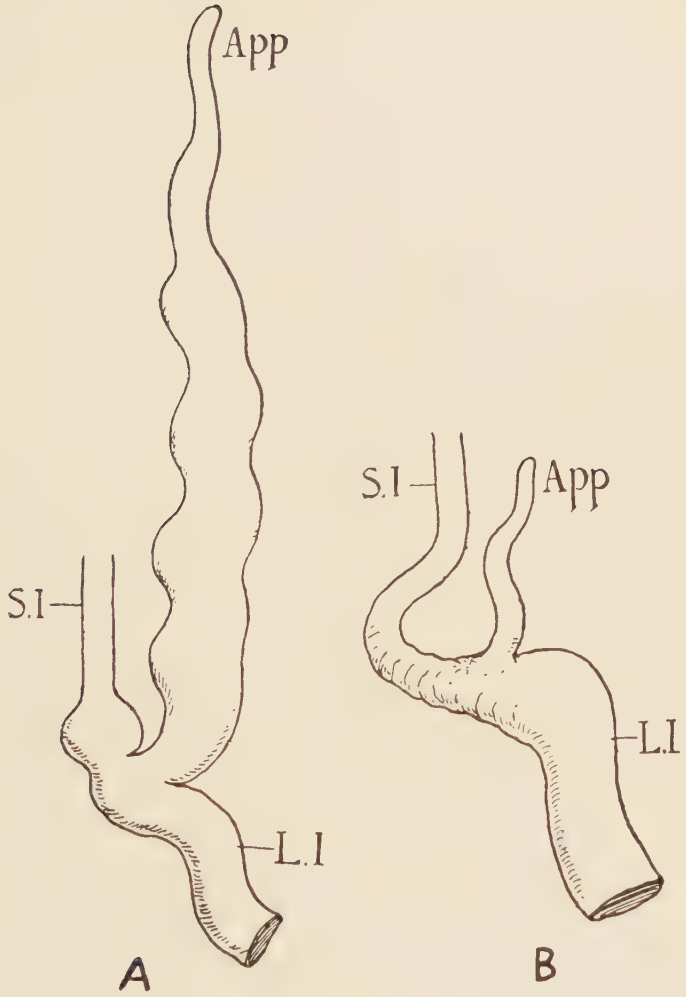


FIG. 40. APPENDICES

A, appendix of rabbit; B, appendix of man; S.I., small intestine; L.I., large intestine; App. appendix. (From Thomson, *Concerning Evolution*. Courtesy of Yale University Press.)

gradually fallen out of use; organs which performed definite functions in our animal ancestors, but which, in us, have lost their physiological importance. They have become useless in consequence of our adaptation to new circumstances, but yet are transmitted from generation to generation by heredity, and have only slowly atrophied.[3]

Before this portion of the morphological evidence is closed, mention must be made of those animals which show resemblances that link them to more than one distinct group of the animal kingdom. These are really transitional types, bridging gaps which designate definitely the manner in which evolution has proceeded. In the chapter on the tree of animal evolution it was indicated in what ways the primitive chordates resembled the invertebrates, on the one hand, and the vertebrates, on the other. From this standpoint the primitive chordates must be regarded as of tremendous importance in helping us arrive at some conclusion concerning the manner of origin of the true vertebrates. Another transitional form mentioned was the primitive mammal known as the duck-bill, which, as was pointed out, in certain respects resembles the birds, and in others the mammals. Strictly speaking, it is a form which lies between the true birds and the typical mammals. Still another interesting form is the invertebrate organism known as Peripatus. Peripatus is linked to the typical annelids in that it possesses regularly arranged paired nephridia or excretory tubes, simple eyes, and stump-like feet; and it also resembles the arthropods, par-

[3] *The Evolution of Man,* New York, G. P. Putnam's Sons, 1910.

ticularly the insects, in the possession of paired mouth parts, a pair of antennæ, and tracheal tubes for breathing.

Other transitional types could be mentioned, but these few will serve to illustrate the point. They are links which bind together the distinctive divisions, the so-called phyla, of the animal kingdom. The evolutionary interpretation of the origin of animals gives meaning and vital significance to these transitional types, regarding them as stages through which the higher forms that resemble them undoubtedly passed in their evolution. J. Arthur Thomson, in discussing Peripatus, puts the situation very well with respect to all transitional types of organisms when he says:

> The point is that Peripatus and its relatives have many Annelid characteristics and many Insect characteristics, and while they are not to be regarded as the actual connecting links between segmented worms and air-breathing, jointed-footed animals, there can be little doubt that the ancestors of insects passed through a grade of organization not far removed from that represented by Peripatus.[4]

2. Serology

Broadly speaking, serology may be said to deal with the fundamental chemical nature of the protoplasm that underlies the organism, particularly that which comprises the so-called circulatory fluid, whether it be the

[4] *Concerning Evolution,* New Haven, Yale University Press, 1925, p. 77.

sap of plants or the blood of animals. In recent years numerous workers have shown that in animals closely related from the standpoint of comparative anatomy, there are certain essential physical and chemical identities within their blood. This demonstration has been due largely to the efforts of scientists such as Reichert and Nuttall; the former working on the crystals produced by the hemoglobin of the blood stream, and the latter concentrating his attention on the so-called precipitin reactions which take place in the blood when foreign substances enter it.

The precipitin tests in particular have been instrumental in showing this relationship very clearly. While there are many ways of making these tests, a favorite method is to secure the clear liquid, the serum, from human blood which has been allowed to stand until its solid components have coagulated into a clot, and periodically to inject this liquid into the circulatory fluid of a rabbit. After a few days of such treatment the rabbit is killed and some of its blood drained off and allowed to stand until the clear serum separates from the remaining parts. When a little of this serum is allowed to come in contact with the blood of a human being a white precipitate is formed. The serum of the rabbit which has undergone this treatment is said to be anti-human to that of man. So marked is the reaction obtained with this test that it has been utilized scientifically and legally for purposes of detecting human blood, whether it be in the fresh state or in the form of dried stains or clots of long duration. Another interesting fact established by the precipitin test is the degree

of relationship between the lower organisms and the human species. The closer an animal is to the human being, the more marked is the reaction; the farther away, the less noticeable is the change and the longer it takes for any precipitation to occur. Thus, it is evident that the degree of relationship is shown not only by structural make-up, but also by strength and rapidity of blood reactions.

Professor Schwalbe, in his chapter on "The Descent of Man" in the Darwin centenary volume, says:

> In quite a different domain from that of morphological relationship, namely in the physiological study of the blood, results have recently been gained which are of the highest importance to the doctrine of descent. Uhlenhuth, Nuttall, and others have established the fact that the blood-serum of a rabbit, which has previously had human blood injected into it, forms a precipitate with human blood. This biological reaction was tried with a great variety of mammalian species, and it was found that those far removed from man gave no precipitate under these conditions. But as in other cases among mammals all nearly related forms yield an almost equally marked precipitate, so the serum of a rabbit treated with human blood and then added to the blood of an anthropoid ape gives *almost* as marked a precipitate as in human blood; the reaction to the blood of the lower Eastern monkeys is weaker, that to the Western monkeys weaker still; indeed, in this last case there is only a slight clouding after a considerable time, and no actual precipitate. The blood of the Lemuridæ (Nuttall) gives no reaction or an extremely weak one, that of the other mammals none whatever. We have in this not only a proof of the literal blood-relationship between man and apes, but the degree of

relationship with the different main groups of apes can be determined beyond possibility of mistake.[5]

Human beings themselves show marked differences in their blood reactions, and this fact has enabled medical men to classify the human species into four distinct groups. In cases of blood transfusion it is very important for the surgeon, before the operation is actually performed, carefully to test the blood of the recipient patient so that he may pick out an individual for the transfusion, known as the donor, whose blood reactions are identical with those of the recipient. Unless such precaution is taken, disastrous results may follow within the blood of the recipient, causing such vital disturbances as ultimately to result in death. Aside from the fact that these blood groups in human beings are very distinct, they are also inherited in a definite way, so that often it becomes possible to predict the blood grouping of the offspring from a knowledge of the circulatory fluids of the parents; and, likewise, from a study of the blood of the offspring one may often be in a position to tell something of the blood groupings of the parents. It becomes evident that such information may, on occasion, be extremely important in determining legal questions of disputed parentage. However, one must not, as some writers have done, push this conclusion too far. Dr. Laurence H. Snyder, in a paper on this question, asserts his belief in the heredity of human blood groups, but he throws out a word of caution with regard to the prediction of parentage. He says:

[5] *Darwin and Modern Science,* New York, Putnam, 1909, p. 129.

By gradually accumulating such tests, the determination of disputed parentage will become more and more accurate. A man who fails in several such tests can be considered without doubt as not being the father. It must be remembered, however, that the true father can never be identified by such tests as these. It can sometimes be said that a certain man is not the father of the child; it can sometimes be said that he *might* be the father; but it can never be said that any man *is* the father.[6]

As a result of such experimentation as has been described above the following conclusions have been formulated. In the first place, the blood of higher forms is relatively more complex than that of the lower forms. Also, the closer one organism is to another, the greater the similarity appears to be between the physical and chemical reactions of their blood streams. For example, while all mammals resemble one another closely so far as blood test reactions are concerned, nevertheless those which are closest to the human being, such as the apes, show the most striking similarities to the blood of man. Some botanists hold that a similar differentiation is evident in plants, and various evolutionary trees have been worked out for the plant kingdom, based on the physical and chemical reactions of the cell sap of plants. All of this is extremely important as well as significant, and it bears out exactly what has been disclosed by the other evidences which have thus far been discussed.

The underlying protoplasmic similarity between

[6] "Studies in Human Inheritance. II. The Medico-legal Application of Hereditary Human Characters, with Especial Reference to the Blood Groups," *Journal of the American Medical Association*, vol. 88 (1927), pp. 562–563.

organisms is so striking that it has been utilized by man as the means of alleviating human pain, suffering, and various abnormalities. For a long time the mammals have been used for experimental purposes in order to aid man in his struggle against disease, pestilence, and plague. It has been discovered that many of the forms close to man suffer from similar ailments; furthermore, they react in like fashion to foreign organisms and poisons which enter their bodies and set up serious disturbances. This thoroughly established principle is so well known to all civilized people that it has been utilized by them as the basis for the production of vaccines and antitoxins, which, when injected into the human organism, prevent or overcome the ravages of certain diseases. For instance, it is now common to vaccinate persons against smallpox, diphtheria, typhoid, and hydrophobia. In certain abnormalities of the human body, glandular and other extracts from related mammals have been utilized to good advantage. In cases of thyroid deficiency, the feeding of sheep's thyroid affords relief in most cases. The question of the relationship of the glands of internal secretion to normal and abnormal development has been little understood; but in recent years a start has been made along this line of research, and it is safe to predict that as new discoveries are forthcoming they will not only serve to overcome deficiencies but also help to strengthen the view presented regarding the fundamental identity and similarity of the protoplasm underlying related organisms.

The monkey family, from a physical and mental standpoint, shows the features most closely related to

the human. Comparative anatomy and animal behavior for a long time have strikingly borne out this conclusion. During the last few decades the fundamental chemical identity between humans and apes has been shown to be extremely close, and this knowledge has been utilized in various ways, especially for the purpose of relieving human suffering. Dr. Lull, in his recent book *The Ways of Life*,[7] says that a diseased thyroid gland of a young boy was replaced by a healthy thyroid gland from a chimpanzee, with apparently no bad effects; and the transplanted structure has been functioning in a normal manner in the throat of the boy. In another case, the bone of a monkey was transplanted into the leg of a man, and here also the structure has been functioning properly in its new location. Facts such as these indicate the kinship of organisms, showing that the closer the resemblance between their anatomical make-up, the greater their chemical similarity is and the more it becomes possible for them to intermingle without deleterious effects. The opposite also holds true; the wider the gap between their make-up, the less resemblance they reveal in their basic chemical constitution. Not only is structural organization a basis of complexity and relationship, but fundamental protoplasmic constitution is also a similar basis of kinship.

These facts lend themselves to no other interpretation than the evolutionary one. The reason that closely related forms show similar organization, behavior, and underlying chemical identity is because they undoubtedly have evolved from each other, or from types which

[7] New York, Harper, 1925.

were similar to them that, for some unknown reason, have long since passed out of existence. Advocates of the special creation point of view must explain why there are so many underlying resemblances in all living forms, from the simplest to the very highest. If organisms were created independently, one would expect them not only to have come into existence separately, as the view postulates, but also to reveal a characteristically distinct organization, with little resemblance to other forms.

CHAPTER IX

EVIDENCE FROM EMBRYOLOGY

Embryology deals with the development of organisms before birth; or, speaking more precisely, it is the subject that embraces the history of the organism during the stages before it reaches adult appearance. In some forms, development is a prolonged process in which the organism hatches into numerous free existing stages, each a step toward the adult condition. A cycle of this kind is called metamorphosis, and it may be observed in the development of such well-known forms as the butterfly and the frog. In the butterfly, for instance, the fertilized egg hatches into a worm-like caterpillar, which after living independently for some time becomes quiescent, surrounds itself with a protective covering called a cocoon, in which it continues to transform until it emerges as the adult butterfly. In the case of the frog, the impregnated eggs hatch into tadpoles, which are fish-like in appearance, and after a period of free existence in the water they develop two pairs of limbs, absorb their tails, and undergo various other changes to become the typical frogs with which everyone is familiar (Figure 41). They can then leave the water to pursue an independent existence on the moist shores.

In man, and among the higher animals in general, all of the preliminary stages in embryological development usually are undergone within the fertilized egg itself, before it hatches, so that when the organism is born it has the general appearance of the adult form. In many instances, the animal may be so helpless as to need

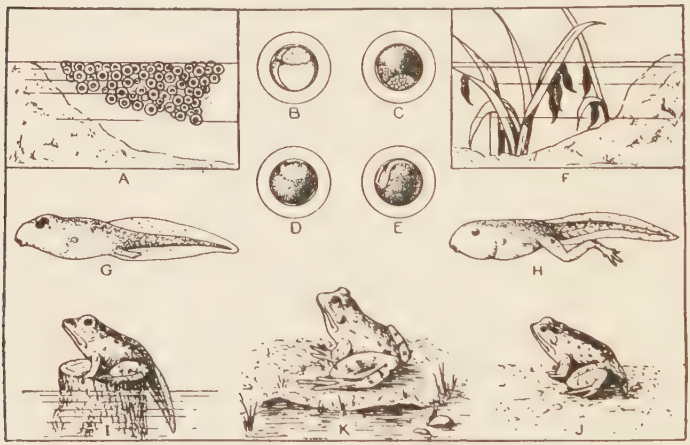


FIG. 41. METAMORPHOSIS OF THE FROG

A, B, C, D, E, various stages in the development of eggs; F, G, H, tadpole stages; I, J, K, later transformations to adult frog. (From Curtis and Guthrie, *Textbook of General Zoölogy*. Courtesy of John Wiley & Sons, Inc.)

parental aid and care, but so far as structure and appearance are concerned it has completed virtually all of its development.

The evidences from embryology are of vital importance in support of the scientist's faith in the evolutionary conception. Although embryology is a fairly old science, only within the last hundred years has it been

studied with any degree of accuracy, and during this time it has yielded many important results affording the strongest kind of evidence in favor of evolution. The outstanding impression derived from studying the embryology of a complex organism is not the logical unfolding of organization from the simple to the complex, but the remarkable resemblance which appears to exist between some of its developmental stages and those of adult larvæ or organisms lower down in the scale of complexity.

The man who first called attention to these striking similarities in the development of organisms was the Dutch embryologist, Carl Ernest Von Baer. During the early part of the nineteenth century this scientist studied the embryology of many animals, the vertebrates in particular, in a comparative way, and found many parallel stages in their development — so many, he concluded, that they must have some significance from the standpoint of origin. In the latter part of the nineteenth century, Ernst Haeckel, after intense comparative study of the embryology of many forms, formulated the biogenetic law in order to bring out the relationship which exists between the individual and the race from which it originated. In ordinary language the biogenetic law states that each individual organism, in its embryological development, passes through the various stages incidental to the development of its race. Technically the law reads: "In the ontogeny, the phylogeny is recapitulated." Ontogeny refers to the development of the individual, and phylogeny to the development of the race. To state the law in somewhat

colloquial language, we might say that the individual organism, during its development, really climbs its own family tree.

For a generation after Haeckel propounded this conception, the law was interpreted in its literal sense, and it was heralded as one of the greatest contributions to science. Biologists began to search enthusiastically for parallels in development and pointed to a large number of extremely interesting and valuable facts which substantiated the evolution of organisms. However, they pushed the law to its extreme limit, considering only the striking parallels and overlooking the differences in development. While later research has substantiated the contention of Haeckel in the main, nevertheless it also has made scientists realize that organisms, during their evolution, have changed and adapted themselves considerably, with the result that in many instances during their prenatal development stages have been skipped, or have become so shortened, condensed, or modified that they seem to bear but little resemblance to any other existing types. An embryo is never an adult form of another class of organisms, but strikingly resembles the type which prevails in that particular group. It merely passes through such a stage, never stopping but constantly progressing toward its logical goal. Internally, also, there are like similarities, but the embryo in question is destined from the start to be the form from which it was conceived. These facts, instead of discrediting the embryological evidences, strengthen them, for they indicate the marvelous plasticity which has enabled organisms to adapt themselves

to different conditions of form, organization, and development — and it must be emphasized that this is exactly what the hypothesis of evolution postulates!

In discussing embryological evidence, one must remember that in practically all animals each embryo is formed from a combination of two specialized cells called germ cells, derived from opposite parents. These are known commonly as sex cells and technically as gametes, the male cells being termed spermatozoa, and the female, ova. They are the agents that carry on the immortality of the individual species and also afford the efficient means of perpetuating the race. Figure 42 shows the comparative size of the human ovum and spermatozoön. One of the most striking phenomena in all biology is the fact that the mature germ cells, no matter where found, always are formed in similar fashion and undergo the same general transformations. Figure 43 is a diagrammatic representation of this maturation process, termed spermatogenesis in the male, and oögenesis in the female; and it also shows that when fertilization occurs, each of the sex cells contributes a representative package of protoplasmic material, consisting largely of nuclear structures known as chromosomes, to form the zygote, the initial start of the new individual. As will be shown later, the chromosomes of the mature gamete really represent the heredity of the particular parent from which it was derived. Therefore, the union of the two germ cells brings in two streams of hereditary potentialities from opposite parents, and these coöperate to produce the new individual. Some of these potentialities seem to be stronger

than others, showing up in the offspring, and are spoken of as dominant characteristics, whereas those which do not make their appearance, although they are present in the new individual, are called recessives. Often the

FIG. 42. HUMAN GERM CELLS

A, an ovum, after Waldeyer; B, a spermatozoön. Magnified about 400 diameters. (From Arey, *Developmental Anatomy*. Courtesy of W. B. Saunders Co.)

representatives of traits brought in by opposite sex cells influence one another to such an extent that a blend occurs, resulting in an appearance which is different

from that of the independent traits contributed. Frequently an entirely new character crops out, and such variations are the ones that make possible the develop-

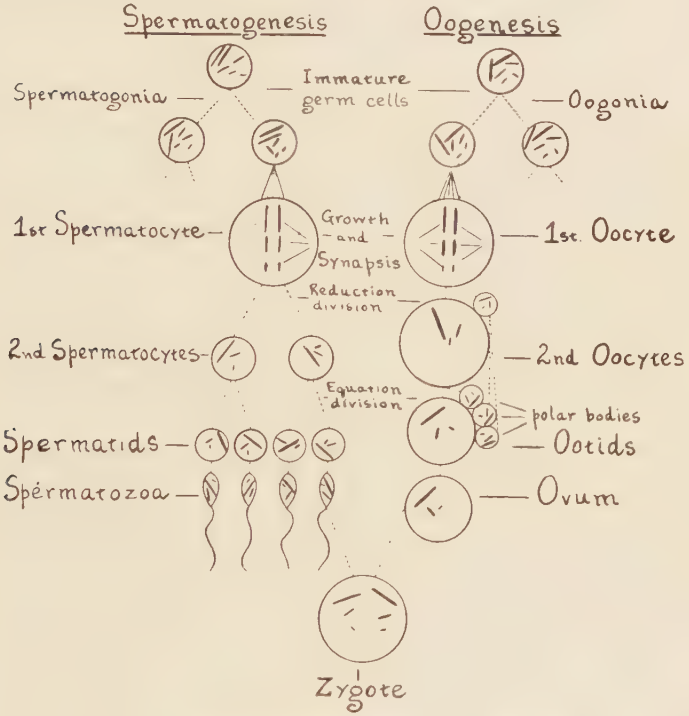


FIG. 43. TRANSFORMATION STAGES OF GERM CELLS

Spermatogenesis is maturation of the male gametes; oögenesis is maturation of the female gametes; zygote is the union of male and female gametes in the process of fertilization.

ment of new varieties, species, or types. Phenomena such as have been indicated are of universal occurrence throughout the animal as well as the plant kingdom,

and although there is considerable difference of opinion as to what accounts for the new variations, nevertheless, they afford additional strength to the view that all units of the living world show a remarkable kinship, which is the basis for our belief in its evolution.

To illustrate the biogenetic law, the development of the human being will be considered, in order to indicate the salient points which bear on evolution. This description will not take into consideration all of the transformations, but will cover merely the chief representative features which signify man's connection with the rest of the animal world. The reason why the human being has been taken for illustrative purposes is that man is more interested in himself than in any other organism, and also because, from a physical and mental standpoint, he is the most complex animal in existence. The geological record of animal life reveals that man is one of the most recent organisms, remains of his early existence having been discovered only in the newest of the earth's strata. It must, therefore, have taken man the longest time to evolve to his present stage. Since these are the facts, we should expect man to undergo the most complicated embryological development, and also to climb the entire tree of animal evolution, showing steps which resemble the principal limbs, that is, the principal groups of the animal kingdom. The actual record of his embryology confirms practically all of these deductions.

Man, like any other organism, begins as a single-celled structure, formed by the union of two germ cells, specialized portions from opposite parents. At this stage

the human being may be said to resemble the single-celled protozoa; or, to put it differently, he starts his development where the animal kingdom begins, at the lowest level of the evolutionary tree. Gradually this single-celled structure, through a process of cell multiplication known as cleavage or segmentation, changes

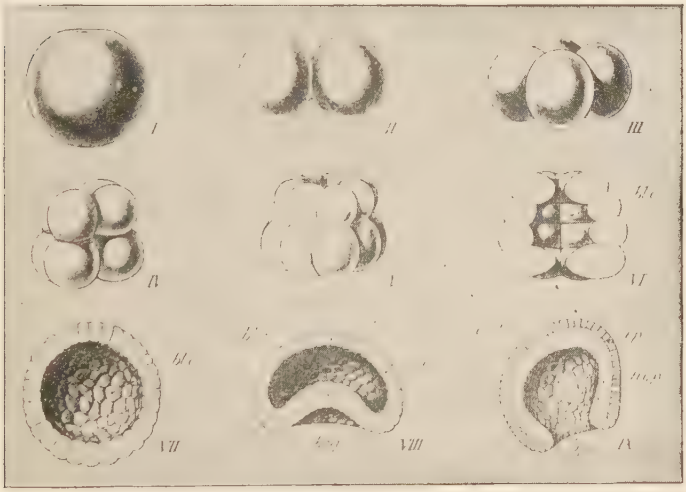


Fig. 44. Early Development of Amphioxus

I–V, cleavage; VI–VII, vertical sections of blastula stages; VIII–IX, vertical sections of gastrula stages. (From Dendy, *Outlines of Evolutionary Biology*. Courtesy of D. Appleton & Co., New York.)

into a mass of cells, comparable in many ways with the colonial protozoa, or sponges, which consist essentially of a ball of similar cells united into a cohesive mass. Following this, the gastrula, a jellyfish-like organism, is formed. It will be recalled that the coelenterates are forms which stop at the gastrula stage in development.

Figure 44 shows cleavage and gastrulation in Amphioxus. A similar though slightly modified process occurs in man, but it must be remembered that the human embryo is destined to become a human individual, not a jellyfish, so that it continues to develop and change until it forms an organism which is worm-like in appearance, reminding us of the trochophore, or of the derivatives of this larva. At this point, the human embryo has some of the characteristics of a typical worm-like organism. Its body consists of a repetition of many segments, in a number of which are to be found paired tubules, comparable with the nephridia of the annelids, and which later become united on either side to form composite kidneys.

After a little more growth, this worm-like embryo transforms and takes on the appearance of a primitive chordate, somewhat similar to the fish-like form Amphioxus; and as will be recalled, the primitive chordates are types which bridge the gap between invertebrates and vertebrates. The next stage is distinctly fish-like in character, in which may be distinguished definite gill clefts, and a circulatory system so organized as to remind one, in many particulars, of the conditions found in an adult fish. In later development, the gill clefts either disappear or become modified into definite portions of the throat, and the fish-like circulation assumes more human characteristics. Following the fish-like appearance, the human embryo undergoes successive stages which, either outwardly or inwardly, resemble to a marked degree the amphibians, reptiles, birds, and finally mammals. When the mammalian level

has been reached the embryo has almost completed its development, and is in possession of the typical mammalian characteristics: the body is covered with hair, the posterior portion of the spine is elongated into a tail, and the various other internal and external features are those of a typical mammal. The human being passes through the early stages of mammalian development and then reaches the status of the higher mammals, resembling such forms as the pig, dog, cat, and monkey. Finally it emerges into the stage where we recognize it as a human being. All of this goes on during the first three months of development, and it is significant that in this short period of time the embryo climbs its own ancestral tree. While the resemblances to the various phyla of animals are not absolute, they are sufficiently striking to be recognized without difficulty. During the last six months of gestation, the embryo increases in size and grows more human in appearance, producing those physical and mental traits which distinguish man from the lower orders of animal life.

How shall we interpret this wonderful unfolding which goes on during the embryology of the human being? Is it merely accidental that there are certain stages bearing marked resemblance to the lower forms, or does it have some basic meaning from the standpoint of the origin of the human family? Biologists believe that it is no accident; they are convinced that it tells us the story which is embodied in the biogenetic law, and that it thereby affords some of the strongest evidence for evolution. It is evidence which is not isolated but

parallels admirably the other evidences from the fields of classification, morphology, and paleontology.

When one studies comparatively the embryology of such involved animals as the vertebrates, one is impressed with the remarkable similarities which they exhibit during the various stages of development (Figure 45). With minor distinctions, the representatives of the

FIG. 45. SIMILARITIES IN EMBRYOS OF VARIOUS VERTEBRATES

(From Romanes, *Darwin, and After Darwin,* after Haeckel. Courtesy of The Open Court Publ. Co.)

different classes of vertebrates undergo concurrent transformations from the moment when the egg has been inseminated to the time when the fish-like stage has been reached. The embryos which are destined to be fishes stop here, hatching and ultimately changing into the species that populate the waters of the earth. Those

belonging to the Amphibia pass through the fish-like stage to form the various members of the class Amphibia. The reptiles ascend all of the preceding rungs of the embryological ladder, and go one step beyond the amphibian height to become snakes, lizards, or turtles. The birds carry this development one notch higher, becoming the feathered creatures with which we are familiar. The mammals, embracing the most complex animals, undergo the most complicated development, during which they climb all of the branches of the tree of animal evolution, finally becoming specialized on the highest limb to form the specific representatives of the group in question. It is thus seen that all animals in their development reveal the same interesting features, as set forth in the biogenetic law, and the natural question is: what is the significance of this parallel unfoldment divulged by animals during their embryology? If only one animal showed it, the conclusion that it is merely accidental might be justified; but since all animals disclose a corresponding prenatal ascent — bearing in mind, of course, that there is some variance in intricacy with the complexity of the group to which the form in question belongs — it cannot be purely fortuitous. So universal is this recapitulation in the animal kingdom that it has given origin to the biogenetic law, which in its broad essential features is accepted by all biologists as the strongest kind of proof for the evolution of organisms.

While the biogenetic law applies to entire organisms in a generalized way, nevertheless one must be cautious not to expect the resemblances to be absolute. As has been indicated, every individual type, even though it

shows stages strongly reminiscent of adult forms or embryos of organisms lower down in the scale of evolution, is in reality quite distinctive in its progress of unfolding, proceeding logically until it reaches the level of the species which it is destined to be. Often many steps have been skipped over or new ones interpolated, masking development to such an extent that little similarity to the lower forms can be seen. The reader, however, must bear in mind that this is exactly what is involved in the idea of evolution; namely, change, transformation, and adaptation between the organism and its environment.

When one studies individual structures and systems of organisms, one finds that the biogenetic law applies much more accurately, because many of these show a logical sequence in development, revealing resemblances which bear a striking similarity to the adult appearance of these portions as they are found in the lower types. In a preceding chapter, the development of the mammalian heart was considered, and there it was shown that this organ starts as a single-chambered structure and progressively transforms into a two-, three-, and four-chambered organ. It was also pointed out that these are the conditions encountered in the adult hearts of the various classes of chordates, beginning with the single-chambered heart of the primitive forms and ending with the four-chambered type of the mammals. The nervous system shows a similar recapitulation in its development. When one compares the nerve cells, or neurons as they are called, of fishes, amphibians, reptiles, birds, and mammals, one can trace a logical advance-

ment; and it is important to note that a like evolution is found to occur during the embryological development of the neurons of man, the highest mammal. Figure 46 illustrates this phenomenon in a most striking manner. Although many other comparisons might be made, the

FIG. 46. EVOLUTION OF THE NERVE CELL

(After Ramon y Cajal. Courtesy of Yale University Press.)

few given will serve to elucidate the principle taught by the biogenetic law; namely, the logical evolution of complexity within the various branches of the animal kingdom.

The more complicated an animal is, the more of the essential steps in the tree of animal evolution it will reveal during its embryology. In this chapter, the

vertebrates, beginning with the fishes and ending with man, were particularly stressed. The morphologist, dealing with structural organization, has classified these organisms in an ascending series, based largely on resemblances and differences in degrees of complexity. The paleontologist, who considers the facts disclosed by the fossil record, also tells us that these forms came into existence upon our earth in logical succession; the fishes first, then the amphibians, reptiles, birds, and mammals. This last-named class includes the most recent organisms to make their appearance, and it doubtless required the longest time for them to ascend to their present heights. Embryology checks admirably with these other evidences, as can be ascertained readily from the facts mentioned in this chapter.

Those who assert that the evidences for evolution drawn from the field of embryology are merely accidental, must explain why the essential features embodied in the biogenetic law are encountered so universally throughout the entire animal kingdom. Why should man, in his development, go through all of the stages which remind us of the present groups of animals lower in the scale of evolution than the mammals, and finally pass through the mammalian level to reach the highest pinnacle, the species *Homo sapiens?* Why should a fish undergo a transformation similar to that of the early development of man, but stop at the fish-like stage? If this has no meaning, and is purely a coincidence, then we have here one of the most peculiar phenomena in all nature, in which animals, widely divergent from the standpoint of organization and

adaptation, have produced the same essential features of embryological development. The biologist cannot possibly regard this as a mere chance; he believes that it tells a wonderful story of interrelationship between the various branches of the animal kingdom, revealing not only their complexity of organization, but also their logical sequence of evolution.

CHAPTER X

HISTORY OF EVOLUTIONARY THOUGHT

The present controversy concerning evolution has given many people the impression that the subject is one of recent origin. As a matter of fact, it is very old, dating back to the ancient period of Greek thought which flourished before the Christian era. Some historians say that it goes back even farther than that; that traces of evolutionary conceptions are to be found in the Oriental thought which dominated the Mediterranean world long before the Greeks rose to their highest pinnacle of achievement. These, though, are mere conjectures. However, as Dr. Henry Fairfield Osborn [1] points out, we do find definite records of evolutionary ideas in Greek writings, and therefore we will do well to begin our discussion with the Greek period.

Greece was at its intellectual height between the sixth and the fourth centuries B.C. Galton has pointed out that in this relatively short period that small territory, no larger than the State of Rhode Island, produced some twenty-five of the most illustrious names that the world has ever known. Among them were several scholars who propounded evolution. Some, like Thales (624–548 B.C.), advocated that everything came from water. Observing that all plants and animals contained water, that

[1] *From the Greeks to Darwin*, New York, Macmillan, 1908.

they were constantly giving off water and periodically had to replenish their systems with water, they concluded that water was the essential source of all life. This, of course, was an evolutionary conception, though a rather crude one. Another group of thinkers gathered around Anaximenes (588–524 B.C.) and promulgated the theory that living forms were the result, not of water, but of primitive slime. It is interesting to note how this idea has cropped out over and over again in the history of evolutionary thought, modified only by the increased knowledge concerning life. These early Greeks said that all living matter was composed of a slimy material, which in reality was the basis for the organization of the various types of animals and plants. They also believed that complete complex organisms originated spontaneously from combinations of minute particles of slime and were stimulated to activity under the influence of the heat engendered by the sun's rays.

There were others who argued that living matter was much more complicated than this; for instance, the famous Greek thinker Empedocles (495–435 B.C.) said that when nature was examined it was found to be an expression of two main forces: love, an attracting power, and hate, a repelling power, acting on the four essential elements — water, air, earth, and fire. Organisms were the resultant products of combinations of these elements plus the action of the two forces of love and hate. Although this conception of Empedocles was very crude, nevertheless it was the first attempt to picture the strife or struggle for existence which is going on in nature. To Empedocles all things represented the

outcome of a clash between the forces of love and hate. Many scientists have called him the father of modern evolutionary ideas, for he not only reduced nature to the essential primary elements, but also taught that there had been a succession in nature: the first forms were very simple, and the later ones much more complex. Furthermore, he believed that the plants evolved first and that in due course of time they were followed by the animals.

The greatest of the Greeks, however, was not Empedocles, but Aristotle (Figure 47), who lived between the years 384 and 322 B.C. He probably was the most advanced thinker that Greece produced, and remains one of the most famous individuals in the history of humanity. Aristotle was prominent in a number of fields: poetry, art, philosophy, and, above all, science. He wrote numerous books on natural history, and many of his observations, made more than two thousand years ago, are just as valid today as they were then. Oftentimes he is called the father of natural history, for he studied many animals and plants and was the first scientist who attempted to classify them on the basis of common characteristics and complexity of organization. After much study he came to the conclusion that there was a gradual change and progression in both the organic and the inorganic world. He said that all nature was united, and that everything in it was working out its destiny, slowly, gradually, but progressively. Such a contention is, of course, exactly similar to that which is enunciated by the modern theory of evolution. In answer to the query concerning what in nature was

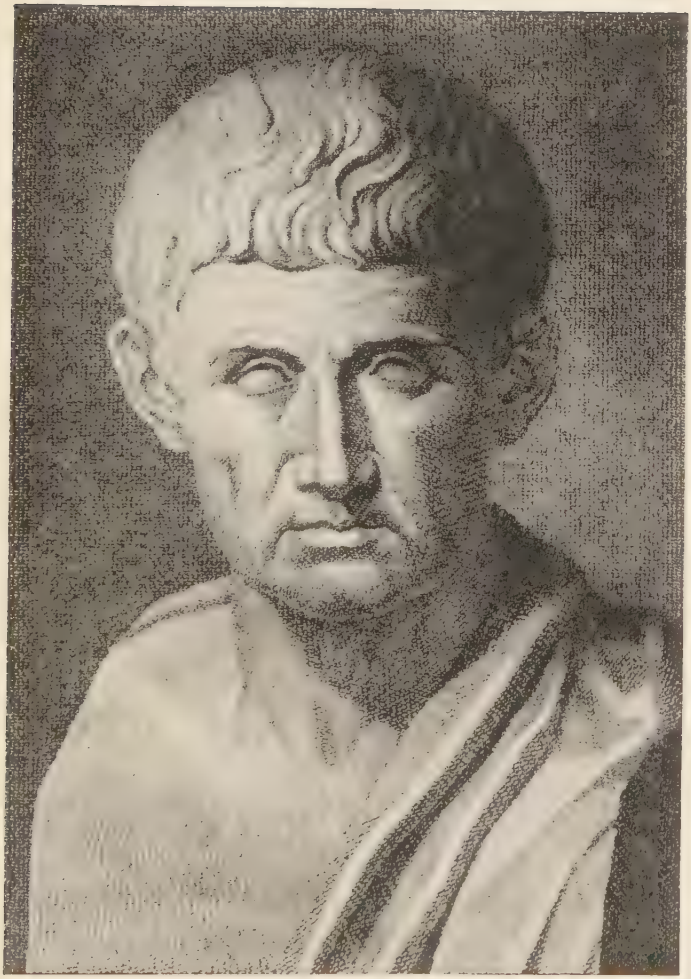


Fig. 47. Aristotle

responsible for the modifications that bring about the evolution which is going on in the living world, Aristotle developed what is known as a perfecting principle, which he called an Entelechy. He stated that in every organism there was present an entelechy which caused it to go on existing, transforming, and progressing, thus forcing the individual to unfold to higher and higher levels. He therefore regarded nature as the product of intelligent design, and it is interesting to note that this same conception has recurred repeatedly in philosophy under various names, such as the "inner urge," the "vital spark," the "perfecting unit," the "creative force," the "guiding principle," and so on.

Aristotle dominated the scientific thought of the civilized world from about the fourth century B.C. to the Christian era. When people thought, especially along scientific lines, they thought in terms of Aristotle. Then Christianity arrived on the scene, whereupon science was neglected and soon forgotten. Scientific achievement came to a standstill, for the world in general was too busy with war, persecution, and religious controversies to be concerned with anything else. Now and then an individual made a feeble attempt to dabble in science, but he soon gave it up, for nobody encouraged such zeal or paid any attention to it. Europe then entered into perhaps the darkest period in all history, lasting from a little after the beginning of the Christian era to nearly the close of the fourteenth century. Progress ceased almost entirely, while ignorance, illiteracy, and prejudice reigned supreme. The Church

dominated the State, dictating and prescribing not only the spiritual life of the people, but their political life as well.

There were a few individuals who carried on some scientific discussions. The greatest of these, from an evolutionary standpoint, was the Italian monk, St. Augustine, one of the very early Christian evolutionists, who lived between the fourth and fifth centuries (353–430) A.D. He preached that the Bible should be interpreted liberally, rather than literally, contending that when the Old Testament said that the world was created in six days the word "day" was not to be accepted in the hard and fast sense as a period of twenty-four hours, but as a period of much greater duration. Many within the Church condemned St. Augustine as a heretic, regarding his teachings as directly opposed to Christianity.

The world was not prepared to listen to this liberal monk. Christianity was being established, and the students of the period were absorbed in futile theological controversies. The Church regulated absolutely the educational policies of the State, and no one dared to question its authority. Scholasticism followed in the wake of the Dark Ages, and the greatest minds of the time became engrossed in futile and absurd theological discussions. The masses were ignorant beyond our comprehension, and were held in virtual slavery by the autocratic priesthood. Oppression grew to such an extent that anyone who attempted to dabble in science, which was regarded as the handiwork of the Devil, incurred the wrath of the Church and was

imprisoned, tortured, or burned at the stake as a dangerous enemy of the people. This condition lasted almost to the end of the fourteenth century.

During the eleventh, twelfth, and thirteenth centuries certain events of significance for scientific development occurred. As a result of the Crusades, many Europeans first came into contact with the culture of the Orient, and a goodly number of them, who later returned to their homes, brought back with them the ideas which they had there absorbed. This was important because, although the peoples of Europe had forgotten Aristotle, those of the Orient had not. The Orientals, particularly the Arabians, Hindus, Moors, and Jews preserved and fostered the lore that came out of Greece. A large group of these scholars studied the work of Aristotle, carrying on his thought as well as adding to it. They understood the Greek language, and even dared to translate Greek philosophy and science into their own tongues. Since many of them, especially the Moors and the Jews, were acquainted with the prevailing European languages, these scholars were largely responsible for the Renaissance which swept over Europe in the following centuries.

In 1453 Constantinople fell into the hands of the Turks, and from that moment the gates of Europe were opened to Oriental scholars, many of whom soon spread into all of the well-known European centers. They had preserved and fostered the sciences — chemistry, astronomy, mathematics, medicine, and the ancient philosophies of Greece — and their arrival

in Europe led to an unprecedented renewal of interest in these long-forgotten subjects.

One of the common criticisms of Oriental peoples is that they never have achieved much along scientific lines, and that they never have produced a really great man of science. However, when one realizes the monumental service which they rendered to civilization in preserving and carrying on scientific endeavor during the Dark Ages, one cannot fail to have a wholesome respect for them. From this standpoint, if from no other, they must be considered a great and gifted people. It must be recalled that from the beginning of the Christian era to almost the end of the fourteenth century it was impossible to think freely in Europe. No one dared to carry on any scientific work, for all endeavor had to accord with the doctrines of the Church. Everything was regulated by ecclesiastical prescription, and those who opposed the clergy were excommunicated, persecuted, thrown into dungeons, horribly tortured, and in many instances even burned at the stake. Superstition, mysticism, and fear dominated the times to such an extent that everyone was in servile subjection to the dictates of the ruling clergy.

While this condition prevailed in Europe, a different spirit motivated the peoples of the Orient. They were free to pursue knowledge; unhampered by church doctrine, they were judged solely on the basis of scholarship and achievement. Great academies, libraries, and universities were developed, and around these gathered a host of scholars who studied Greek philosophy and science, and made it the basis for

their own endeavors. They became proficient in alchemy, mathematics, astronomy, and medicine. When Europe's re-birth actually came, they were the only people who had done any constructive work in the sciences, and therefore they were destined to take the leading part in the intellectual reconstruction that followed. Inasmuch as some of these Oriental centers had developed among the European nations bordering the Mediterranean, such as Spain, Portugal, and Italy, these scholars were familiar with the languages current in those countries and therefore could translate into the principal European tongues, not only the ancient Greek works, but also their own contributions, thereby making them available for everybody. Taking everything into consideration, the historian must ascribe great credit to the part played by the Orientals in the intellectual revival that swept over Europe at this time.

Likewise of influence in favor of scientific advance was the fact that the State began to free itself from the ecclesiastical yoke. This meant that the Renaissance was really a threefold process, involving religion, politics, and learning. Definite scientific and evolutionary progress began when men were allowed to think more freely.

In the fifteenth and sixteenth centuries two schools of thought sprang up, largely within the Church, the adherents of which were called, respectively, the literalists and the liberalists. The literalists, led by the Spanish Jesuit priest Suarez (1548–1617), insisted on a literal interpretation of the Bible; they opposed the

Greek philosophy of Aristotle, and insisted on the absolute infallibility of the Mosaic doctrine of creation as depicted in the first chapter of Genesis. The liberalists, on the other hand, like St. Augustine of old, believed in a rational interpretation of scripture. They advocated that the Old Testament be explained in the light of the centuries in which it was written. Their great leader, Giordano Bruno (1546–1600), an Italian priest, was burned at the stake for affirming his belief in the creation of the universe through an evolutionary process. In passing, it is worth while to note that here, as elsewhere, history seems now to be repeating itself. At the present time, a similar controversy is being waged between the fundamentalists and modernists.

Early in the sixteenth century science began to flourish, and evolutionary thought assumed more definite shape. At about this time there lived in England a man by the name of Francis Bacon (Figure 48), who may be credited with ushering in the modern era in science. Bacon, who was born in 1561 and died in 1626, was one of the earliest forerunners of modern evolution, for he propounded the origin of plants and animals by slow steps, through the accumulation of minute, fluctuating variations. In this respect he may be regarded also as a precursor of Charles Darwin. There are those who say that Bacon was not a great scientist and that he did not contribute anything really original. They contend that he was a great popularizer who utilized the experimental evidence developed by other scientists of his time and incorporated it into his own writings in such a way as to give the impression that he was solely

responsible for it. Be that as it may, nevertheless he served a splendid purpose in helping to bring about the establishment of a new method, known as the inductive or experimental method, which plays such an important *rôle* in all science of the present day.

In developing the inductive method Bacon was unquestionably influenced by such contemporaries as Harvey (1578–1657), the great English physiologist, who not only discovered the circulation of the blood, but also was one of the ablest scientific experimenters of the time. Realizing the hopelessness of making any progress by the old methods, Bacon was fully convinced that advancement could come only through a complete modification of the scientific approach. The old method was purely deductive in its nature. Men of science advanced preconceived notions and made everything accord with them. The new method took nothing for granted except that which was discovered to be a fact through experiment. It started with the minute details, checked up on them, and found out more and more about their operation and relationships; and when enough facts had been accumulated, a general law applying to all of them then could be formulated. Bacon's cardinal point was that before making any predictions concerning an object, one should first discover, through direct examination and investigation, how its various parts functioned.

Bacon wrote many volumes, such as the *Novum Organum* and the *New Atlantis*, in which he expounded his views. In the *New Atlantis*, he advocated the establishment of an institution for the study of the sciences

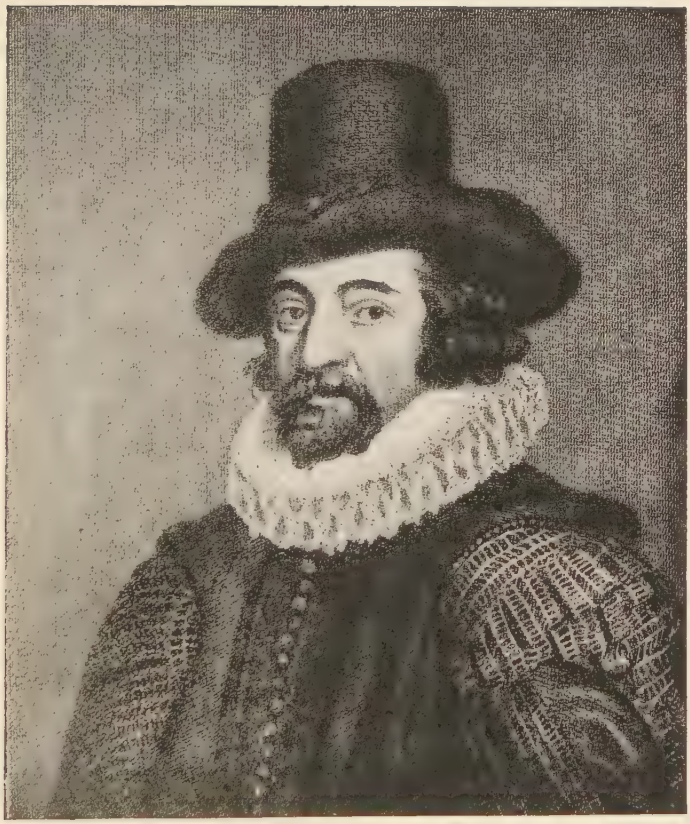


Fig. 48. Francis Bacon

through the experimental method. In this institution he proposed to incorporate laboratories for the study of animals and plants, particularly from the standpoint of their responses, origin, and evolution. Aside from everything else, this was to be a place for the experimental study of the evolution of organisms.

Of course, such a plan was regarded as novel in the sixteenth century, for very few people thought in similar terms. Bacon was considerably ahead of the times in which he lived, and his writings, needless to state, made little impression in his own day. The laboratory method which he advocated is really very young in science, for it was not established until comparatively recent times. Today it would seem strange and futile to teach science in any other way than by the method of experiment, but until seventy-five or a hundred years ago practically all of the sciences were taught primarily by observation and deduction. In appraising Bacon's importance, therefore, one must not forget that he lived at a time when men thought in terms radically different from those of today, and that by insisting on his inductive method he led the way to the establishment of our modern scientific conceptions.

Bacon's influence asserted itself to such an extent that during the few centuries following his death evolutionary thought became more definite. Almost all of the leading philosophers and scientists were evolutionists. In France, Descartes (1596–1650) and Laplace (1749–1827), both mathematicians and astronomers, contended that the universe developed gradually and progressively; in Holland, Spinoza (1632–1677), the pantheistic philosopher, preached evolution; in Germany, Leibnitz (1646–1716) and Kant (1724–1804) also held evolutionary views. Many others could be named, but those who have been mentioned dominated the thought of the times.

Toward the latter part of the eighteenth century, and

in the early part of the nineteenth, three distinct schools of evolutionary thought appeared — in Germany, France, and England — and these paved the way for the modern evolutionists.

In Germany the names of Oken, the scientist, and Goethe, the naturalist poet, stand out preëminently. Oken (1776–1851) advocated that species originated from primitive slime. He noticed that the underlying basis of all living matter was a slimy substance, and therefore he concluded that living things had evolved from some fundamental primitive material similar to it in composition. This, of course, was not a new conception, for some of the ancient Greeks, as will be recalled, held a similar point of view. The Greeks, however, did not possess the knowledge of living organisms that Oken possessed, and consequently could not marshal as many facts to substantiate their primitive viewpoint. Undoubtedly, Oken's contention had considerable influence in the later deduction of the nineteenth century that the underlying basis of plants and animals was the jelly-like, slimy substance known as protoplasm.

The poet Goethe, who lived from 1749–1832, wrote many essays and poems about nature, portraying the unity, coördination, and harmony that exists throughout the living world. He thereby stimulated many people to think along evolutionary lines. Goethe lived and wrote at a time when many of the conceptions which were more completely developed at later periods had their beginnings; consequently, when some of these are examined in the light of our present-day

knowledge, they seem rather crude and dogmatic. Goethe had a keen mind and a wonderful insight into the harmonious unity which pervades all nature. He believed that the greatest thing that man could receive in life was that God-Nature be revealed to him! J. Arthur Thomson says:

> We cannot, in our partiality, repress the futile wish that Goethe had loved poetry less and science more, since his was certainly one of the greatest intellects that has dealt with evolution problems.[2]

George H. Lewes,[3] who was the husband of George Eliot, and one of the first to write a biography of Goethe, devotes an entire chapter to him as a man of science, holding that this poet naturalist must be given much credit for stimulating thought along evolutionary lines.

In France there flourished the school of biology headed by the three great naturalists, Buffon, St. Hilaire, and Lamarck. Buffon (1707–1788) advocated a view that the environment was solely responsible for change, regardless of the functioning of the parts of organisms. He was rather timid in asserting his views, fearing to offend those who believed in the doctrine of special creation. Buffon was really not a great scientist, but rather a fluent writer who possessed the gift of making natural history interesting. He wrote voluminously but superficially, and the value of his work lies in the fact that he made natural history popular at a

[2] *Science of Life,* London, Blackie & Son, 1899.

[3] *The Life and Works of Goethe,* New York, Dutton, 1864.

time when very few people concerned themselves with the subject.

St. Hilaire (1772–1844) held ideas similar to those of Lamarck (1774–1829), who was not only a gifted naturalist, but also the outstanding evolutionist of his time. St. Hilaire defended Lamarck's evolutionary views in debate against Cuvier, the French scientist who advocated the cataclysmic theory of creation. As will be recalled, Cuvier, through his gift of oratory, as well as his social and scientific standing, succeeded temporarily in overthrowing Lamarck's contentions, so that in their own day both St. Hilaire and Lamarck were greatly discredited individuals. In later years biologists began to appreciate the contributions of these men, particularly those of Lamarck, and it is no exaggeration to state that Lamarck's ideas on evolution are more respected today than they were in his own time.

Lamarck made a number of great contributions to evolution. He speculated on nature, on the variety, yet withal the unity, that existed in it. Recognizing an infinite number of links binding the members of the organic world, he finally came to the conclusion that the various representatives of the plant and animal kingdoms originated logically, one from the other. In answer to the question as to how new species arose, he propounded one of the outstanding theories in all science, based on the principle of use and disuse of structures and organs. He stated that every organism fitted itself to its particular environment. All plants, all animals, come into existence with certain numbers of

qualities and characteristics, but in adapting themselves to the conditions under which they live — climate, soil, etc. — they must use certain structures more than others. The parts thus used become emphasized and specialized, whereas those used only in part, or not at all, fall into disuse, dwindle, and finally degenerate.

How does this effect the origin of new species? The used portions are exercised, become efficient, and are stimulated to vary in certain directions; and in time these changes or variations become definitely incorporated in the organism, so that in some fashion they ultimately become a part of the germinal stream and can thereby be transmitted to the next generation. A concrete example will help to clarify the principle involved. Lamarck cited the long-necked giraffe as an illustration. At first, undoubtedly, the giraffe did not have such a long neck — a fact which has been established through the study of fossil remains. At one time the giraffes probably lived in places where they could easily reach the limbs of trees in order to browse on the leaves. The environment doubtless changed, becoming hotter and drier, so that the plants grew taller, with the result that the lower limbs soon died and left the living foliage confined to the uppermost branches. This made it necessary for the animals to stretch their necks to reach the leaves, so that this portion of their bodies slowly but definitely increased to its present length.

In like fashion, on the principle of the disuse of parts, Lamarck accounted for the vestigial structures in organisms. For instance, such a structure as the appendix

in man would be explained by the fact that man, in adapting himself to a changed diet, did not need quite so long an intestine, so that a portion of it fell into disuse. Undoubtedly through generations of disuse this portion dwindled and gradually atrophied, until at the present time it is recognized as a small remnant of its former self. In this connection it is significant, as pointed out in the chapter on evidences for evolution from comparative anatomy, that in purely herbivorous animals the appendix is extremely long, and functions as a definite part of the digestive tract.

Likewise, in England, at about the same time, there were several evolutionists, foremost among them being Erasmus Darwin, the grandfather of the great evolutionist, Charles Darwin. Erasmus Darwin lived in the eighteenth century (1731–1802), and died about seven years before Charles Darwin was born. In 1794 he published a book entitled *Zoönomia,* in which he set forth his ideas on evolution. To some extent he was influenced by the conceptions of the German and French evolutionists, particularly those of Buffon. He arrived at virtually the same conclusions as Lamarck, although it is quite certain that he was not aware of Lamarck's views, since these were published in 1809, seven years after Erasmus Darwin's death. He had a clear conception of the struggle for existence going on among plants and animals, and he also believed that the environment influenced organisms, not directly, as Buffon maintained, but indirectly, by evoking within them changes due to the functioning or non-functioning of the parts. His writings did much to stimulate

thinking along evolutionary lines in England, and thus laid the foundations for a more favorable reception of the views subsequently propounded by his grandson, Charles Darwin.

Another English scientist of this period who directed people's attention to evolution was the geologist Charles Lyell (Figure 49). He was born in 1797 and died in 1875. It may be said that Lyell accomplished for geology what Charles Darwin accomplished for biology. In 1830 he published his monumental work on geology in which he pointed out that the crust of the earth was the result, not of a series of cataclysms, as Cuvier maintained, but rather of a slow, definite accumulation of materials which were deposited in past generations in consequence of logical transformations occurring in various regions. He asserted that such changes were taking place continuously, and he saw no reason why those which had occurred in the past could not be explained in like manner. As for fossils, instead of regarding them, as did Cuvier, as mistakes of the Creator buried deep in the earth, Lyell considered them as actual remains of organisms which had existed in the past, but which, through natural circumstances, had been entrapped within the deposits that were slowly being built up. His book aroused considerable antagonism, especially from theologians, who attacked it with all the vigor at their command.

The popular writer, Robert Chambers (1802–1871), was another Englishman who did much to pave the way for modern evolution. In 1844 he published anonymously a book entitled *The Vestiges of Creation* in

Fig. 49. Charles Lyell

(From Mayer, *The Seven Seals of Science*. Courtesy of The Century Co.)

which he propounded his ideas on evolution. Although he was grossly in error concerning many of his scientific facts, nevertheless he seems to have had a clear insight into the evolutionary forces and processes going on about him. He emphasized environmental influences as stimulating organisms to become modified in definite directions, and believed that these changes had evolutionary significance. Like Aristotle of old, the anonymous author of *The Vestiges of Creation* believed in a perfecting principle which directed and guided organisms to unfold. Charles Darwin, in the historical introduction to his *Origin of Species,* appraises the *Vestiges of Creation* as follows:

> The work, from its powerful and brilliant style, though displaying in the early editions little accurate knowledge and a great want of scientific caution, immediately had a very wide circulation. In my opinion it has done excellent service in this country in calling attention to the subject, in removing prejudice, and in thus preparing the ground for the reception of analogous views.[4]

All evolutionists, from the last half of the nineteenth century to the present time, have been dominated by one outstanding figure, Charles Darwin, who was born in 1809 and died in 1882. In speaking of Charles Darwin, however, we must also mention his contemporary, the English scientist, Alfred Russell Wallace, who lived from 1823 to 1913. Both of these men (Figure 50) must be regarded as the founders of mod-

[4] New York, D. Appleton & Co., 1888, new ed. from the 6th English ed., with additions and corrections.

ern evolutionary thought, inasmuch as independently they discovered the same general principle which underlies the evolution of plants and animals.

It is a striking coincidence that the central idea embodied in their views, namely, natural selection coupled with survival of the fittest, occurred to both scientists after reading an essay on population written by the English clergyman and economist, Thomas Robert Malthus (1767–1834). In 1798 Malthus published his classic *Essay on the Principles of Population as it Affects the Future Improvement of Society,*[5] in which he showed that the human population tended to reproduce more rapidly than the supplies in nature necessary to maintain it. Malthus contended that nature's supplies were really more or less stable, and could support only a limited population. Therefore, there goes on a struggle between man and nature, with the ultimate result that the human family soon adjusts itself, as far as numbers are concerned, to a population which can subsist adequately on the supplies present in the environment. Such environmental agents as food, light, moisture, and the like are the efficient checks which determine the total population.

Darwin and Wallace tell us that they read this interesting dissertation by Malthus about twenty years apart, Darwin in October, 1838, Wallace in February, 1858. Darwin, however, did not publish anything concerning his views, but merely discussed them carefully with some of his intimate friends, particularly the

[5] London: Ward, Lock; reprinted from the last edition revised by the author.

botanist Sir Joseph Hooker and the geologist Sir Charles Lyell. Wallace, on the other hand, relates that when the idea occurred to him, he jotted it down in the form of an essay that same evening; and then, after working on it for two more days, he sent it to his friend Charles Darwin. When Darwin realized that Wallace had fallen upon the same principle, his first impulse was to shelve his own labors and give Wallace full credit for it; but those of his friends who knew of his untiring efforts, running over a period of more than twenty years, interceded and prevailed upon him to write a preliminary sketch of his views, so that it could be published jointly with Wallace's in the *Journal of the Linnean Society of London*. These short papers appeared in the issue for June 30, 1858, giving credit simultaneously to Darwin and Wallace for the view which at the present time goes under the name of the "Darwinian conception of evolution." In 1908, fifty years after the publication of these essays, the Linnean Society commemorated the event by issuing the Darwin-Wallace medal (Figure 50).

Aside from the fact that Wallace had formulated the same idea as Darwin, there was really little comparison between the two men, for Darwin was unquestionably the greater naturalist. He studied nature for many years before he undertook to write much on the subject of evolution, and during that time he collected more facts to substantiate his contention than any other scientist who had ever lived. In 1859, when *The Origin of Species* actually appeared, all doubts in the matter were completely dispelled, for the volume revealed the

many years of patient work which he had put on his principle and also disclosed the great mass of facts which he had marshaled from all parts of the world to uphold his conclusions. If it had not been for the coincidence that Wallace chanced upon the idea of natural selection in 1858, Darwin probably would not have published his book as soon as he did, for he fully intended to check up on his numerous facts for a few more years.

Courtesy of Popular Science Monthly.

FIG. 50. THE DARWIN-WALLACE MEDAL OF THE LINNEAN SOCIETY

Darwin was an extraordinary man, and he left his mark on science for all time. His contributions to evolutionary thought were really threefold. In the first place, he accumulated a large amount of proof for evolution — larger by far than had ever been accumulated by anybody else. In the second place, he was the first individual to show clearly that evolution applies, not only to material things, but also to the psychical realm; that is to say, it holds good for the mind as well as for

the body. The third and last contribution of Darwin was his elaboration of the principle of natural selection, showing clearly how the process of evolution was brought about in nature.

Numerous biographies of Darwin have been written, but the two that stand out most prominently are *The Life and Letters of Charles Darwin,* by his son Francis Darwin,[6] and the recent one entitled *Darwin,* by Gamaliel Bradford.[7] The former is a son's appraisal of his father, whereas the latter is a literary man's evaluation of a great scientist. Both accounts give a splendid insight into the unusual personality of Charles Darwin. He was born in Shrewsbury, England, on February 12, 1809, the birthday of our own Abraham Lincoln. It is a strange concurrence that these two men, destined to play such important *rôles* in the lives of millions of human beings, were born on the same day in such widely separated places.

In his youth and early manhood Darwin was very vigorous, quite normal in his ways, and showed no particular interests or aptitudes, except that he loved to roam about in the fields in search of flowers and birds. His wealthy family sent him to the University of Edinburgh, where for two years he studied medicine; but he did not like it, found lectures uninteresting, examinations difficult and intolerable. He then matriculated in Christ's College, Cambridge, where, after studying for three more years, mainly along lines of divinity, he finally succeeded in winning his bachelor's

[6] London: John Murray, 1888.
[7] Boston, Houghton Mifflin, 1926.

degree. In later years Darwin looked back on his college career as a period of struggle, with dull courses and hard examinations which he barely managed to pass. The one great interest that he showed throughout all of these years was for the science of natural history.

Upon his graduation he was recommended by his teacher of natural history, Professor Henslow, for the position of naturalist on His Majesty's ship, the *Beagle,* which was then being equipped by the British Government, mainly for the purpose of exploring the western coast of South America. Darwin spent five years (1831–1836) on this voyage, and upon his return he published a delightful volume entitled *A Naturalist's Voyage in the "Beagle,"* [8] which gives an interesting account of his observations in the many lands visited during the expedition. This journey was highly significant for Darwin's later development, for upon it he began to think along the many lines which later converged in the publication of his numerous volumes. During this trip, moreover, he developed his cardinal ideas on evolution, so that, all in all, the voyage of the *Beagle* may be said to mark the turning-point in his career. Although Darwin left England a strong, healthy young man, his digestion became permanently impaired while on the trip, so that for the rest of his life he was virtually a cripple. He never could be cured of his malady and was forced to live quietly, with only two hours a day allowed for work. However, this did not seem to diminish his cheerfulness. Bradford tells us that he was a good father and a good husband; and that in his

[8] New York, Dutton, ed. of 1906.

two hours of daily work he accomplished more than the ordinary person could accomplish in a full day's effort.

His main work, *The Origin of Species,* was published in 1859, and it is extremely difficult for us to form even a vague conception of the stir that it produced in intellectual circles. Since people had not been accustomed to think in terms of evolution, on all sides Darwin's theory became a target for attack. The Church stood solidly against him, as did also a large number of the leading scientists of the time. He had a few staunch supporters, and their number steadily increased as his work became better known. Thomas Henry Huxley (1825–1895) in England, and Ernst Haeckel (1834–1919) in Germany, did monumental work in championing Darwin's cause before the masses of their own countries. In America, Dr. Cope (1840–1897) and Dr. Marsh (1831–1899), paleontologists, also helped to advocate and vindicate his theory.

To Huxley (Figure 51) belongs the greatest credit for untiring efforts in behalf of Darwinian evolution. Huxley had the unique gift of being able to make abstract scientific principles intelligible to the masses, and he used this gift generously in the cause of evolution. He was not only a fine scientist, but also a skillful logician, and engaged in numerous debates with prominent opponents of evolution. One of his debates, with the English Bishop Wilberforce, has become famous because it indicated Huxley's keen and subtle gift of repartee. In the biography of him written by his son, we are told that at the meeting of the British Associa-

Elliott and Fry Photo.

FIG. 51. THOMAS HENRY HUXLEY

tion held at Oxford, in 1860, Bishop Wilberforce terminated a sentimentally flippant address against the *Origin of Species* by asking Huxley whether it was through his grandfather or his grandmother that he claimed his descent from a monkey. To this Huxley replied:

> I asserted — and I repeat — that a man has no reason to be ashamed of having an ape for his grandfather. If there were an ancestor whom I should feel ashamed of recalling, it would rather be a *man* — a man of restless and versatile intellect — who not content with success in his own sphere of activity, plunges into scientific questions with which he has no real acquaintance, only to obscure them by aimless rhetoric, and distract the attention of his hearers from the real point at issue by eloquent digressions and skilled appeals to religious prejudice! [9]

Huxley not only used logical oratory in his debates, but, what was even more important, he employed common sense and scientific facts. His six lectures to workingmen, published under the title of *Darwiniana*,[10] cover all of the main points that Darwin set forth, in such a clear-cut and simple manner that the average layman has no difficulty in understanding them. It took Huxley nearly ten years to establish Darwinism in England. In Germany, Ernst Haeckel (Figure 52), who frequently is alluded to as the "Darwin of Germany," did a like service in establishing the Darwinian

[9] Huxley, Leonard, *Life and Letters of Thomas Henry Huxley*, New York, D. Appleton & Co., 1900, vol. 1, p. 199.

[10] New York, Appleton, 1893.

principles. Haeckel's books and essays, and particularly his popular lectures at the University of Jena, attracted the attention of many intellectuals from all parts of Europe. As the result of such efforts, in about fifteen years after the publication of *The Origin of Species*, the scientific world became almost unified in its acceptance of the evolutionary views of Darwin.

Courtesy of Scientific Monthly.

FIG. 52. ERNST HAECKEL

At the present time Darwin easily stands out as the preëminent leader among evolutionists. No one has ever overthrown his chief contentions in spite of the fact that there has grown up in certain quarters a tendency to discredit some of them. Since the most important of these factors will be discussed critically further on, at

this point only the main features of his scheme of evolution need be outlined.

The Fertility of the Organic World. — The fact is well established that organisms in nature are very prolific; a great many more come into existence than can ever develop to maturity. Darwin realized this and recognized that such productivity, unless held in check, would presently populate the world with so many of a single species that everything else would be crowded out. An illustration will serve to clarify this point. The oyster of the Pacific Coast, *Ostrea lurida,* produces about one million eggs during the breeding season. If all of these eggs, after fertilization, developed into mature oysters, and if they in turn propagated in like numbers, it would take only a few years before the waters would be so completely filled with oysters that there would be no place left for other organisms. As everyone knows, however, such is not the case; the probability is that comparatively few of the fertilized eggs ever reach maturity.

The Operation of Heredity and Variation. — Heredity accounts for the resemblances between related organisms, and by means of it the fundamental characteristics of parents are handed on directly to the offspring. While, in the main, offspring resemble their parents in those basic traits which are common to all members of the strain, nevertheless during their lifetime they can also acquire new characteristics which, on occasion, might become permanently incorporated into their hereditary stream. It must be mentioned, in passing, that Darwin, like Lamarck, believed in the

transmission of acquired modifications. The acquisition of such new characteristics, differing from the old ones, is really what is implied in the term variation. Darwin took into consideration two classes of variations, those which were minute, fluctuating or continuous; and the sudden, discontinuous, and more easily distinguished ones, often called sports or mutations. The former, occurring more commonly, he regarded of primary significance in evolution; the latter, being rather infrequent, he believed of minor importance.

The Limitations of the Environment. — Nature's supplies, such as food, oxygen, water, etc., are limited and can support, from year to year, only a certain fixed number of organisms. Therefore the environment must be looked upon as an efficient check making it impossible for more forms to exist than can be adequately maintained. Darwin was all the more firmly convinced of this after reading the Malthusian essay on population already referred to.

The Struggle for Existence. — Because of nature's limited supply, there is constant strife going on between different forms for the possession of the things necessary for the maintenance of life. The more organisms found within a locality, the fiercer becomes the struggle for existence and the greater becomes the mortality of those incapable of holding their own.

Survival of the Fittest Through Selection. — According to Darwin, those types which are best fitted through heredity and variation to cope with the conditions of the environment, survive and continue to exist; the others soon fall by the wayside and in many instances

pass out of existence without leaving any offspring. The culling-out process is really a matter of selection. Darwin emphasized three selective agencies operating to bring about such survival: (1) Natural selection, in which nature herself chooses the organism for survival. This is a blind force which functions in such a way as to put a premium on types possessing those variations which enable them to meet the vicissitudes of their particular environment. Darwin emphasized this kind of selection above all others, and because of it his evolutionary hypothesis is often referred to as "natural selection." (2) Artificial selection, in which man is the directing agent, giving preference to variations which suit his fancy. Many of the forms developed in past generations by plant and animal breeders have been due largely to the relentless and persistent choice of desired traits. It is a question whether, in a state of wild nature, the modifications selected by man would stand any chance of survival; but be that as it may, it is a fact that many new varieties and species have been produced in this manner. (3) The last agent to be mentioned is sexual selection, in which sex plays its part in picking out the individuals to perpetuate the species. In many forms there goes on a strenuous rivalry for mates, and although there has grown up a popular belief that the female is deadlier than the male, in that she picks and chooses her mating partner, nevertheless the real facts show that in many groups the female has little choice and invariably is forced to accept the male who has been successful in killing or driving off his adversaries. A very interesting example

of how such sexual selection works out in nature has come from Dr. George H. Parker's studies [11] on the mating behavior of the seals on the rookeries of the Pribilof Islands near Alaska. Several years ago these islands were set aside, by international decree, as breeding-places for the fur-seal herd of the Pacific Ocean. During the mating season a fierce conflict goes on among the mature males, bulls, for possession of the females, cows. It has been shown that when the cows arrive on the rookeries the bulls engage in a terrific fight and the one which either vanquishes the others, or succeeds in chasing them off, becomes the lord and master of the harem of females in his territory. The females have no choice in the matter but must passively accept the victorious male. One bull usually becomes associated with a colony of many cows, varying in number from a few up to a hundred individuals, and he becomes the progenitor of all of the young born in the group.

The Origin of Species. — This is the result of the operation of all of the above factors, particularly survival of the fittest through natural selection.

As stated previously, fifteen years after Darwin published his *Origin of Species,* science whole-heartedly accepted his doctrine, which met with universal approval. It must be emphasized that the essential basis of his theory of the origin of species rested on the points of natural selection, the inheritance of acquired modifications, and the cumulative effect of small

[11] "The Fur-Seals of the Pribilof Islands," *Scientific Monthly,* vol. 4 (1917), pp. 385–409.

fluctuating variations. In Darwin's time no one questioned these factors, and therefore they became the cardinal ones in the accepted plan of evolution.

Toward the latter part of the nineteenth century scientists began to examine some of the details of Darwin's evolutionary hypothesis more critically, and additional contributions began to make their appearance. August Weismann (Figure 53), who was born in 1834 and died in 1914, was one of the first to doubt the Lamarckian view of the inheritance of acquired modifications; and as a result of his studies he came to the conclusion that such transformations could not be handed down from one generation to the next; in other words, they could not be inherited. He therefore put forth the so-called " Germ-Plasm Theory " of heredity, which asserts, in brief, that only those characteristics make their appearance in offspring which are originally a part of the germ cells that produce them. Weismann thereby relegated variation and its transmission to the germ plasm, insisting that only those differences which had their actual beginning within the germ cells could be handed on to the next generation. In practically all other respects Weismann's views accord with the broad features of the Darwinian conception.

Another contribution which made its appearance after Darwin's time was the emphasis on sudden variations, resulting mainly from the work of the Dutch botanist, Hugo De Vries (Figure 54), who, born on February 16, 1848, is still living in Holland. This scientist found that several new varieties and species originated suddenly and spontaneously among evening

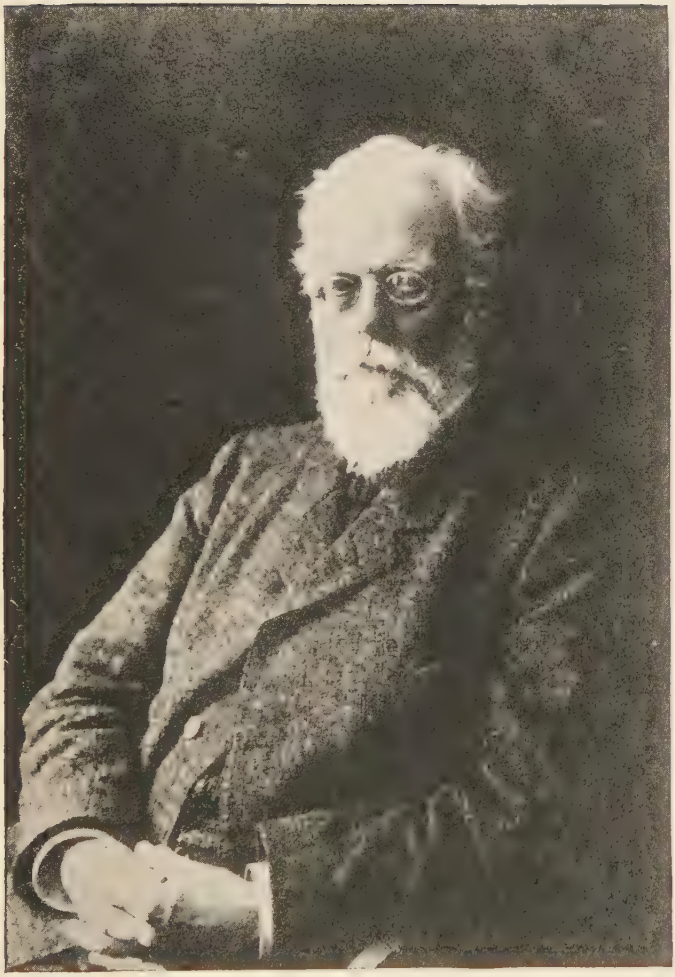


FIG. 53. AUGUST WEISMANN

(Courtesy of The Open Court Publ. Co., and *Genetics*.)

primroses. After studying them at great length, he became convinced that this was the only manner in which new forms evolved in nature. Now, there are numerous biologists who emphasize mutations as the only means by which evolution can be accomplished. Darwin, of course, knew of mutations, but, because he regarded them as large modifications of rare occurrence, he accorded them a place of secondary importance, stressing principally the small, minor, or fluctuating variations.

In 1900 the so-called Mendelian principles of heredity were re-discovered, and these have aided biologists to obtain a real insight into the manner in which traits behave during heredity, so much so that variation, heredity, and even evolution in large measure have become experimental and exact sciences. Inasmuch as these principles are discussed further on, little need be said about them here. However, one fact must be emphasized — that the founder of the principles, the Austrian monk Gregor Mendel (Figure 55), who lived from 1822 to 1884, discovered them at about the same time that Darwin published his monumental work. But since Mendel's conclusions appeared in an obscure Austrian journal, and, since the scientists of the time were too engrossed in examining Darwin's contentions, they remained unknown until their re-discovery in 1900. It is hard to say what effect they might have had on Darwin, and particularly to what use he might have put them.

Another addition to evolutionary thought made in recent years has been the elaboration of the principle of orthogenesis, which emphasizes variations in the

Courtesy of Scientific Monthly.

FIG. 54. HUGO DE VRIES

direction of a straight line, irrespective of environmental influences. According to the advocates of orthogenesis, evolution of types and species has frequently been brought about through the agency of certain

FIG. 55. GREGOR MENDEL

(From Punnett, *Mendelism*. Copyright 1919 by The Macmillan Co. Reproduced by permission.)

variations which began to develop and progressed unmolested in a definite manner, often passing the stage where they appear to be of service to the individuals. The German biologist, Theodore Eimer, and the

Austrian botanist, Carl von Nägeli, have been the chief proponents of orthogenesis.

Isolation has also been emphasized as a means of bringing about evolution. This has been discussed in the chapter on animal distribution, particularly as it affects the fauna and flora that are cut off from central areas by various barriers. Moritz Wagner in Germany, George J. Romanes in England, David Starr Jordan and John T. Gulick in the United States, have been the strongest advocates of the isolation principle.

All of the really important contributions to evolutionary thought have been made in comparatively recent years. In spite of the wide and divergent points of view which confront the present-day student of the problem, the basic facts of evolution as enunciated by Darwin and his co-workers are still accepted by nearly all scientists. There is no difference of opinion concerning the broad fact of evolution; the disagreement manifests itself only when specific factors are considered. Bearing this in mind, let us now investigate more thoroughly the factors which are operative in the grand spectacle or process of evolution.

CHAPTER XI

BASIC FACTORS OF EVOLUTION

As stated more than once in the preceding chapters, the fact of evolution is now generally accepted by scientists, but in regard to the factors of evolution there are considerable differences of opinion. The evidences for evolution are so striking and so universally encountered in nature that all who are willing to examine them without prejudice become firmly convinced of their validity. On the other hand, as regards the inherent forces responsible for evolution, it must be admitted frankly that scientists still are trying to uncover the exact means by which the process is brought about. The factors of evolution will be discussed under two general headings: first, those that are basic or essential for all evolution; and second, those that are causal, or directive, in originating new types. These are so interrelated that it is extremely difficult to say where the one ends and the other begins.

The basic agencies significant in evolution are heredity and variation, by means of which all progression in nature has been made possible. Biologists agree that these are the foundations upon which the whole structure of evolution rests. In recent years, therefore, they have received a large amount of attention, with the

result that an independent field of biology, called genetics, has been developed. In a somewhat restricted sense, the science of genetics deals with the heredity, or resemblances, and variation, or differences, exhibited by organisms related by descent. In a broader sense, it deals with heredity and variation as exhibited by groups of organisms; or, to put it differently, with the origin and transmission of those resemblances and differences which are revealed by the various groups of animals and plants that populate the earth.

It is undeniably true that more has been accomplished in the field of genetics since the year 1900 than was accomplished in all of the preceding centuries. In the last twenty-five or thirty years biologists have been able to determine the manner in which many traits are transmitted, and also to make some progress in understanding the origin and potency of variation. It is significant that even though studies along these lines at times have been disappointing, yet the little advancement which has been made has resulted in the establishment of several new varieties of organisms showing a combination of characteristics a little different from those inherent in the original species from which they were derived. The study of the basic factors of evolution has been of tremendous help in revealing an experimental means of bringing about some degree of evolution. Therefore it is important, before the causal factors of evolution are considered, to treat of the basic factors of heredity and variation involved in all processes of evolution.

1. Heredity

The subject of heredity deals with the underlying facts and principles which account for the resemblances exhibited by organisms related by descent. Phenomena of heredity are so commonplace that they have given rise to many proverbial expressions such as "like begets like," "a chip off the old block," "the apple does not fall far from the tree," etc. Scientifically, heredity involves a thorough familiarity with the structure and organization of living forms, as also with their mode of origin and development. In the chapter on embryology it is stated that almost all organisms start developing as single-celled individuals, called zygotes, formed by the union of two definite portions of parents, known as germ cells. It is also pointed out that each of these germ cells brings in a representative group or package of determiners for characteristics, and that these determiners coöperate to form the resultant new organism. The cell, particularly the germ cell, therefore must be looked upon as essential for everything which the new individual possesses, and hence must be considered the basis for heredity.

Our knowledge of the cell dates from the years 1838–1839, when two German biologists, Schleiden and Schwann, propounded the cell theory, according to which the fundamental structure of plants and animals is similar in character, being composed of cells. This is one of the most significant generalizations in modern science, and it has given origin to a distinct branch of biology known as cytology, having for its aim the study

of that unit of organization of living matter, the cell. In recent years this structure has been investigated with great zeal, due, primarily, to its important *rôle* in life processes. From a morphological standpoint, all organisms consist either of single cells or of many cells; from a physiological standpoint, the functions of the organism may be said to be a summary of the activities of its cells; and from an embryological standpoint, the individual starts its development as a zygote, a single cell formed by the union of two germ cells derived from opposite parents. The cell, therefore, is regarded as the foundation for the construction, functioning, and development of the organism.

In Chapter VIII, on the evidences for evolution from morphology, the essential make-up of the typical cell was described. As will be recalled, it is a complex structure consisting mainly of three essential parts: the central nucleus, possessing as its most important element heavily-staining granules known as chromatin; the cytoplasm, a more or less homogeneous mass surrounding the nucleus; and the centrosome, either a single or double granule lying within the cytoplasm next to the nuclear wall (Figure 32). The nucleus is considered the dynamic center of the cell, and its chromatin is regarded as the carrier of those entities, chemical or otherwise, which account for the hereditary qualities. During cell division (Figure 56), the chromatin is definitely organized into distinct bodies called chromosomes, and these now are credited with being the transmitters of the hereditary determiners from one generation to the next.

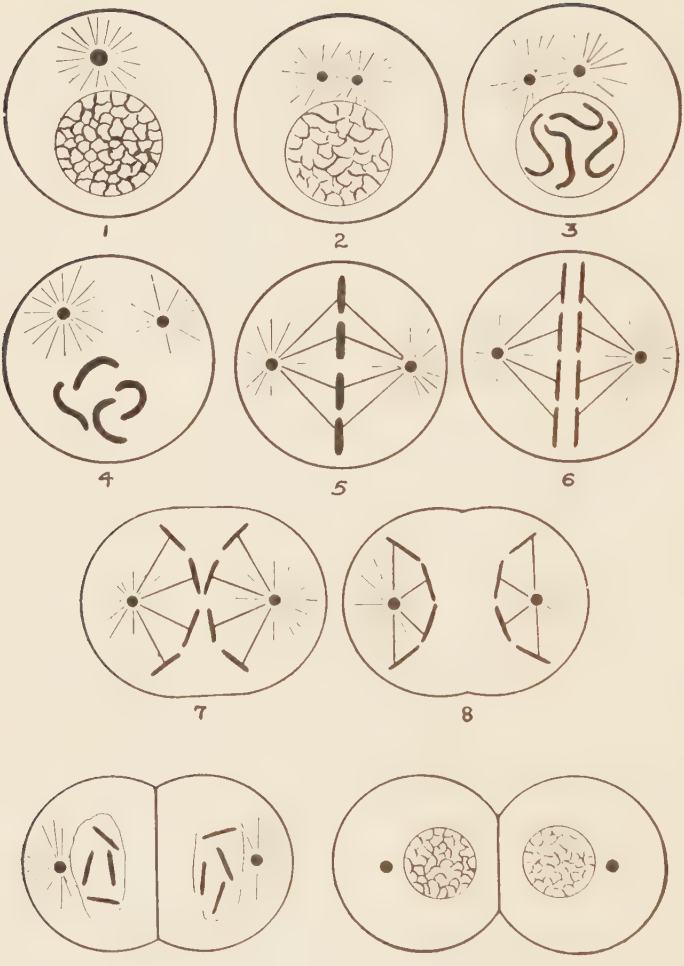


FIG. 56. STAGES IN CELL DIVISION, OR MITOSIS

1–4, prophase, where cell is prepared for division; 5–6, metaphase, where chromosomes line up in equator and split into halves; 7–8, anaphase, where chromosomes are pulled to opposite poles and where cytoplasm divides; 9–10, telophase, where division of cell is completed.

Two types of cells are found in organisms: somatic cells, which occur in the body proper or constitute the somatoplasm; and germ cells, which are found in the reproductive organs, forming the germ-plasm. The first are concerned with the vegetative functions of the body, that is, growing, feeding, etc.; the second reproduce the species. According to Professor E. B. Wilson, the outstanding leader in the field of cellular biology, "heredity is a consequence of the genetic continuity of cells by division, and the germ cells form the vehicles of this transmission from one generation to another." [1] In other words, the physical basis of heredity lies within the germ cells.

2. Theories of Heredity

Numerous theories have been propounded concerning the relationship between heredity and the germ cells. In the eighteenth century Haller put forth the theory of "preformation," according to which the germ cell, either the egg or the spermatozoön, was believed to contain a completely formed individual resembling in every detail the adult from which it was derived. Two schools sprang up around this point of view, one known as the Spermists, which looked upon the male germ cell, or spermatozoön, as the one which possessed the pre-formed organism (Figure 57); the other known as the Ovists, which regarded the female germ cell, or ovum, as the carrier of the minute individual. In either

[1] "Heredity and Microscopical Research," *Science*, vol. 37 N.S. (1913), pp. 814–826.

case, the function of the opposite germ cell which united with the one that carried the miniature organism was merely to feed and stimulate it to complete its development. This hypothesis gave way to Bonnet's "emboîtement" or "encasement" theory, according to which the germ cell contained not only the individual which immediately followed, but also all individuals which were to come thereafter. Thus it would appear that Mother Eve held, within her germ cells, diminutive models of all human beings of past, present, and future generations.

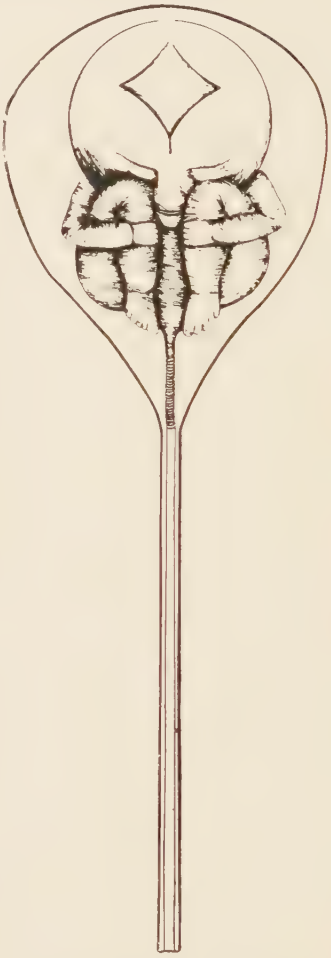


Fig. 57. Human Spermatozoön, Showing Pre-formed Organism

In 1759 Caspar Friedrich Wolff, by his studies on the embryology of the chick, demonstrated the absurdity of the various preformationist views. Wolff showed that there was no pre-formed embryo within the germ cell; that it was, rather, a simple structure without any vis-

ible degree of organization, which, through a complex process, unfolded to become more highly specialized and organized into its particular form. Wolff put forth the "epigenesis" view, which states that the germ cell consists of simple elements or stuffs, and that these by growth and development become organized into more intricate structures. His theory paved the way for a more rational interpretation of development and heredity, and may be said to have been largely responsible for the two hypotheses which stood out so prominently in the nineteenth century, namely, Darwin's theory of "pangenesis" and Weismann's "germplasm" conception.

In 1868 Charles Darwin published a book [2] in which he propounded the theory of pangenesis, a view to account for the inheritance of characteristics from parents to offspring. According to Darwin, all cells comprising the body were supposed to bud off minute particles, the so-called gemmules or pangens, which made their way into the blood stream and were then carried to the germ cells, where they were stored. Each germ cell was, therefore, nothing more than a storehouse filled with representative pangens from every part of the organism (Figure 58 A). According to pangenesis, then, the germinal elements were formed from bodily structures; in fact, they were dependent upon the body for their final organization. Naturally, any somatic or bodily modification would be ultimately represented through the budded-off pangens within the

[2] *Animals and Plants under Domestication,* 2nd. ed. rev., 1875; New York, Appleton, authorized ed., 1896.

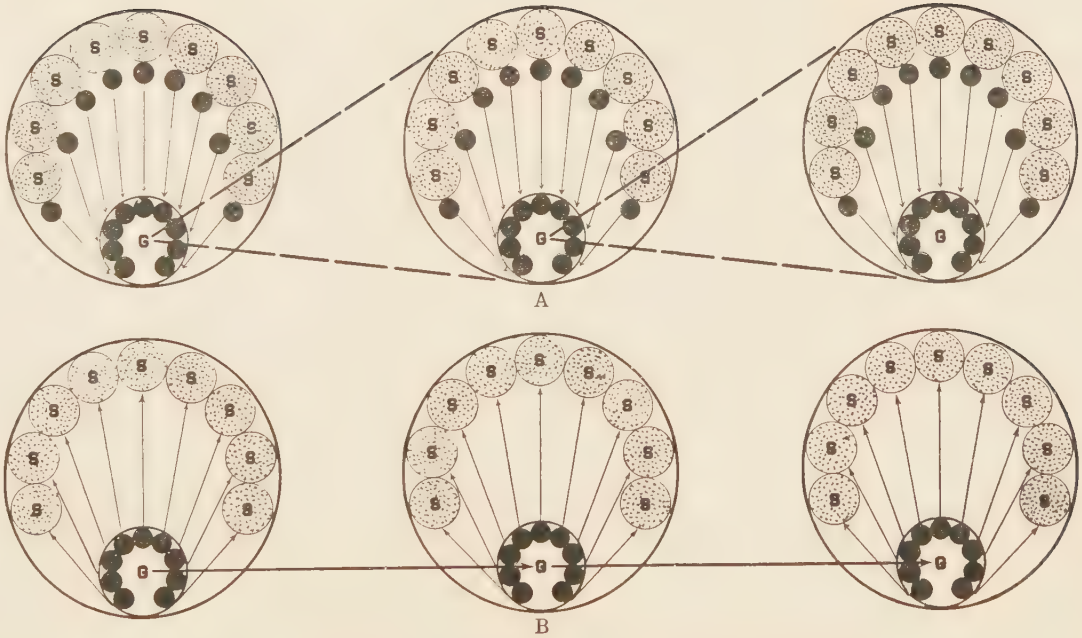


FIG. 58. DIAGRAM OF PANGENESIS AND GERM-PLASM CONCEPTIONS

A, pangenesis view; B, germ-plasm conception; S, somatic structures; G, germ cells. In A, the black circles designate pangens or gemmules; in B, they represent germinal determiners.

germ cells. Development was looked upon as merely the growth and elaboration of these small particles, so that the majority of scientists accepted the view as an excellent explanation of the heredity of acquired bodily characteristics.

Toward the end of the nineteenth century the conception of pangenesis was seriously questioned by numerous investigators, notably by the German biologist August Weismann, who performed experiments which seemed to show conclusively that somatic modifications were not inherited. For some twenty successive generations Weismann docked the tails of rats, but the offspring continued to be born with unimpaired tails. He argued, therefore, that the germ cell was the forerunner of the body and not the result of it and that both bodily and germinal elements arose by differentiation from the undifferentiated zygote. Before differentiation had proceeded very far, the germ cells were distinctly set apart from the somatic cells, so that apparently they played no further *rôle* in development, except that they increased in number by division, and at sexual maturity underwent maturation into the gametes capable of reproducing the species. Weismann saw this early segregation between body and germ cells in his studies on the development of hydroids, and since his time numerous investigators have pointed out similar phenomena in various other organisms. On the basis of his investigations, Weismann argued that, although the germ cells constituting the so-called germplasm, and the somatic cells composing the somatoplasm originate side by side in the fertilized ovum, yet

the former was to be looked upon as continuous and immortal, carrying the heritage from generation to generation in one endless stream, whereas the latter was to be regarded as discontinuous, passing out of existence with the termination of the life cycle of the individual (Figure 58 B). According to this view, only those traits which happen to be found in the germ cells could make their appearance in offspring, while those acquired by the body cells were only passive or transitory and could in no way affect the hereditary constitution of the next generation.

This theory of the continuity of the germ-plasm, propounded by Weismann in 1885, has stimulated a great deal of research, especially along cytological lines. Weismann regarded the body as the container and nourisher of the germ cells, but not as the manufacturer of them. The germ cells were supposed to carry the determiners for hereditary qualities in a restricted portion found within the nucleus, particularly within the chromatin or chromosomes; and this latter conception, in a somewhat modified form, is today accepted by most biologists. However, when it comes to regarding the germ cells as absolutely distinct from body cells, neither exerting any influence upon the other, there are numerous modern biologists who dissent from such an absolute viewpoint. These dissenters are of the opinion that both germ cells and somatic cells are differentiated portions of a united organism, and on occasion, not only may the one influence the other to change in definite directions, but both may simultaneously be subjected to similar stimuli so as to bring about permanent modi-

fications. While it is true that, in the main, the germinal make-up accounts for the largest part of the hereditary constitution of the individual, nevertheless the effects of the somatic structures must not be disregarded, for at times they also may afford the means of change along specific lines.

The group of biologists who are of this opinion are in full agreement with Dr. Child when he asserts:

> Since the germ-plasm theory has found its adherents chiefly among zoölogists, it is natural that the attention of zoölogical investigators should have been attracted to the question of the early segregation of the germ cells from the somatic cells. If the germ-plasm is really a distinct and separate entity independent of the soma, and is continuous from one generation to another, we should expect the germ cells to be segregated from the somatic cells at the beginning of embryonic development. Thus far, however, no case has been discovered in which such a segregation occurs, although in various animal groups a more or less complete segregation apparently does occur at an early stage of development. In other groups, among the animals, no indication of such segregation has ever been observed, although theoretical considerations have led many zoölogists to believe that even in such cases a segregation occurs, but without visible differences between germ cells and other cells.[3]

In spite of these differences of opinion, all biologists believe that the vehicle for the transmission of hereditary traits lies principally within the chromosomes in the nucleus of the cell. Therefore, it is essential for

[3] *Senescence and Rejuvenescence,* Chicago, University of Chicago Press, 1915, p. 324.

us to consider the reasons for regarding these bodies as the carriers of the heritage.

3. Chromosomes and Heredity

One of the most striking characteristics of the chromosomes is that every species of plant or animal possesses a constant and definite number of them, which may vary considerably even in closely related forms. For instance, in the somatic cells of the common American crayfish, *Cambarus virilis,* there are two hundred chromosomes, whereas in those of a closely related form, *Cambarus immunis,* there are two hundred and eight. In various types of Pacific Coast edible crabs of the genus Cancer, similar differences in number appear. In the parasitic threadworm, *Ascaris megalocephala,* found in the intestine of the horse, there are four chromosomes within each of the body cells, while in those of *Ascaris lumbricoides,* a parasite of the human intestine, there are forty-eight chromosomes.

Besides this numerical constancy for species, the chromosomes often are found to possess a distinct individuality of size and shape, which can be recognized in nearly all stages of cell division (Figure 59). This fact has been interpreted to signify that the chromosomes vary among themselves qualitatively, and that each of them bears determiners for distinct and different qualities represented in the adult organism. Weismann emphasized this view more than any other investigator. He regarded each chromosome as a package of minute substances called "ids," and these he

FIG. 59. INDIVIDUALITY OF CHROMOSOMES

As seen in immature male germ cells of: A, the grasshopper, *brachystola magna* (after Sutton); B, the squash bug, *anasa tristis* (after Wilson); C, the mosquito, *culex* (after Stevens).

believed to be the entities which reproduced the characteristics of the parent. In recent years Professor Thomas Hunt Morgan and his co-workers have mapped the chromosomes of the fruit fly *Drosophila* to indicate the location of the specific units, now called genes, responsible for the characteristics which appear in the individuals (Figure 60).

Another point of interest in connection with the chromosomes is that in the early undeveloped germ cells of an animal the same number of chromosomes is found as in the body cells, in contrast with the fact that only half the somatic number is present in the mature gametes. An examination of the immature germ cell reveals the presence of two of each type of chromosome. Thus, if the different kinds of chromosomes be represented by the letters A, a; B, b; C, c; etc., there will be two A's (A, a), two B's (B, b), two C's (C, c), etc. When the germ cells undergo development or maturation, this double or *duplex* number of chromosomes is reduced to one-half, or *simplex* number, with the ultimate result that every gamete contains a single representative of each pair of chromosomes. This is accomplished by a pairing of homologous chromosomes, A with a, B with b, C with c, during the period of the growth process of maturation known as synapsis; and a double splitting of each pair through the agency of cell division occurs, one division being reductional and the other equational. The reduction division, undoubtedly, brings about the segregation of the paired hereditary entities, whereas the equational division produces nothing new as far as heredity is concerned, but merely increases

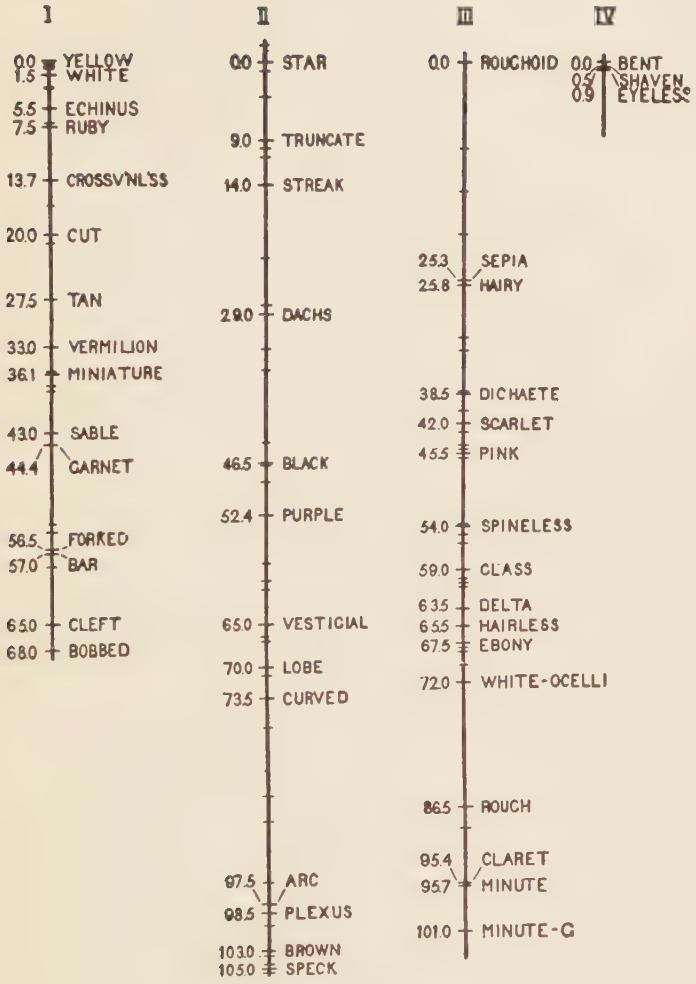


FIG. 60. LOCATION OF GENES IN CHROMOSOMES

The chromosomes are those of the fruit fly *drosophila.* (From Morgan, *Evolution and Genetics.* Courtesy of Princeton University Press.)

the number of sex cells by two. Figure 61 shows the essential things which take place during the reduction division.

Maturation of germ cells is a universal process in all organisms that reproduce by the sexual method.

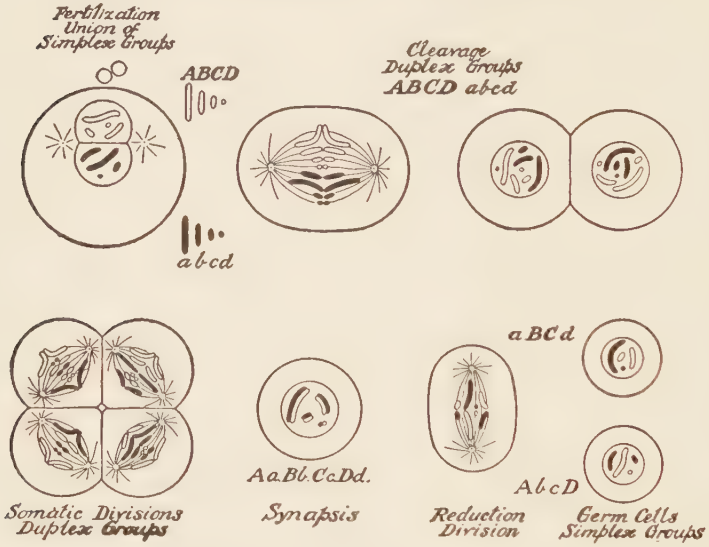


FIG. 61. FERTILIZATION AND CLEAVAGE STAGES OF THE DEVELOPING EMBRYO

The single sets of chromosomes A, B, C, D, and a, b, c, d, brought in by opposite germ cells, unite to form the duplex set, and these are equally distributed in the formation of the body cells and immature germ cells. In the maturation of the germ cells, this double set is reduced to the single or simplex set through synapsis and the reduction division. (From Wilson, "Heredity and Microscopical Research," *Science,* vol. 37.)

Apart from minor differences, the essential steps are similar to those indicated in the diagram, Figure 43.

Perhaps the most significant phases of the entire process are those involved in growth, synapsis, and the reduction division. In order to undergo reduction in the number of chromosomes from the somatic or duplex set to the germinal or simplex set, the homologous pairs of chromosomes line up compactly, either side by side or by twisting around each other. In the former case, the reduction division probably brings about the complete separation of the original distinct pairs of chromosomes, while in the latter it undoubtedly causes a segregation and union of representative portions of the original pairs, so that each of the resultant chromosomes is really a combination consisting of some entities from the father's side and some from the mother's. The more the twisting occurs, the greater is the possibility of an admixture through "crossing over," as the twisting is called, of the hereditary determiners from the maternal and paternal sides (Figure 62).

The fact must be remembered that the primitive germ cell, since it is derived from the embryo, possesses the determiners for the two sets of characters brought into the embryo by the union of the male and female reproductive elements. In other words, the germ cell before maturation really represents both the maternal and the paternal characteristics. In modern genetics the adult characters themselves are called unit-characters, while the germinal entities responsible for them are known by various names, such as factors, determiners, or genes. Maturation is merely a device for separating the representatives for these paired characters, so that in each of the mature gametes only one

set of them is present, either maternal or paternal in origin, or containing some derived from one parent and others from the opposite parent (Figure 63). Although the mature germ cells are known to differ tremendously in size, the egg being very much larger than the sperma-

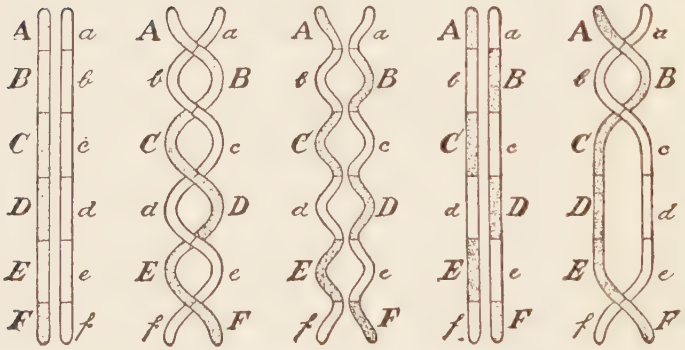


FIG. 62. INTERACTIONS AMONG CHROMOSOMES

Twisting, crossing over, and separation of homologous pairs of chromosomes during synapsis and the reduction division of the maturation of the germ cells. (From Wilson, "Heredity and Microscopical Research," *Science*, vol. 37.)

tozoön, yet they are found to contain about the same amount of chromatin material. In fertilization, the male and female elements each contribute the simplex number of chromosomes, representing factors or genes for single sets of unit-characters. The intermingling of

these restores the duplex or somatic number to the embryo. All this has been strikingly confirmed by Mendelian breeding, as we shall see further on. This type of breeding work bears out exactly what has been sus-

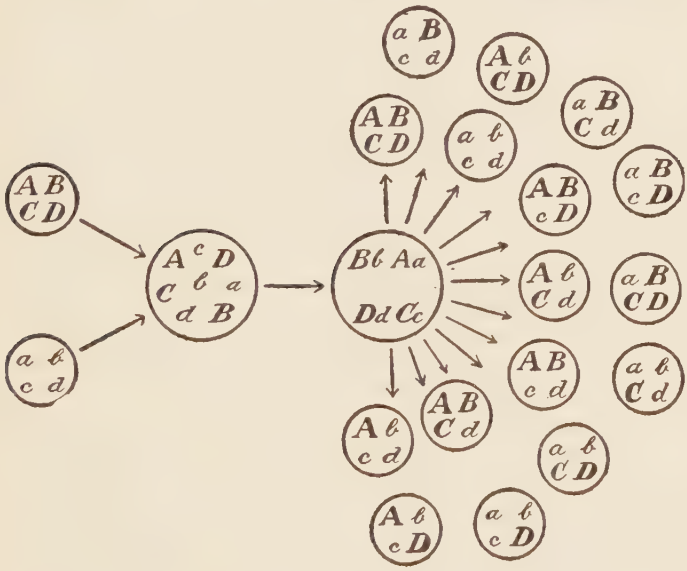


FIG. 63. POSSIBLE GAMETES RESULTING FROM VARIOUS FACTORS

The sixteen types of gametes possible where four pairs of factors, A, B, C, D and a, b, c, d, that is, Aa, Bb, Cc, Dd, are considered. (From Wilson, "Heredity and Microscopical Research," *Science*, vol. 37.)

pected to occur during the maturation of the germ cells, namely, the segregation of the determiners for unit characteristics derived from the opposite parents that engender the offspring.

The strongest evidence for our belief that the

chromosomes are the bearers of heredity comes from two lines of inquiry: first, from experiments in crossing distinct species, and second, from investigations on the problem of sex determination. A careful examination of the facts revealed by such research leads to only one conclusion — that entities within the chromosomes are responsible for the transmission of parental traits.

In connection with the first line of evidence, the work of Boveri may be mentioned. He succeeded in fertilizing enucleated (i.e., nucleus removed) eggs of the sea-urchin *Sphaerechinus,* with the spermatozoa of another species of sea-urchin called *Echinus;* and the resulting larvæ showed only paternal, that is *Echinus,* characteristics. In later experiments by Boveri, Loeb, Morgan, Godlewski, and others, the complete eggs of the sea-urchin were fertilized by spermatozoa of another species of sea-urchin or mollusc, and in every instance the resultant larvæ possessed maternal characteristics; but in each of these cases it also was shown clearly that, although the spermatozoön entered the egg, it was thrown out during the early stages of embryonic growth, seeming thus to contribute nothing to the development of the individual. These experiments point to the nucleus as the storehouse of the heritage, and since the chromosomes are the most constant structures of the nucleus, and, for that matter, of the entire cell, they must be regarded as the all-important elements in hereditary transmission.

Probably the most significant evidence to support the chromosomal view of heredity rests on the discovery that the sex of numerous animals depends, mainly, on

a specific chromosome or group of them within the germ cell. For a long time the problem of sex has been considered a great mystery. Various views have been promulgated to account for the sex of the embryo. The early naturalists believed that environmental conditions such as food, temperature, moisture, etc., were the controlling factors. More than five hundred theories originated, each offering some pet solution of the problem. Geddes and Thomson, writing in 1889, state:

> The factors which are influential in determining sex are numerous, and come into play at different periods. The constitution of the mother, the nutrition of the ova, the constitution of the father, the state of male element when fertilisation occurs, the embryonic nutrition, and even the larval environment in some cases, these and yet other factors have all to be considered.[4]

Without further discussion of the subject we may say that there are no positive data to show that sex is determined by any of the above-mentioned influences.

Recent cytological research has brought to light a considerable amount of evidence which seems to point to special chromosomes within the germ cells as being the sex determiners. While there are a few investigators who still ascribe sex determination to different agencies, nevertheless most biologists now believe that the sex of an embryo is established soon after, if not at the time, fertilization occurs; and that in the majority of instances the zygote develops into the individual which it is destined to be. Of course, the surrounding medium

[4] *The Evolution of Sex,* New York, Scribner, 1900, pp. 34–35.

in which an embryo matures might radically interfere with its normal development so as to bring about considerable modification, but in most instances this environment cannot influence it to produce a differently-sexed individual than the one that it started out to develop. In fact, it must be asserted emphatically that thus far no one has succeeded in controlling sex.

4. Sex Determination

Prior to 1891, it was thought that all of the germ cells of a species possessed the same number of chromosomes. In that year, however, Henking showed that in the bug *Pyrrhocoris* two types of spermatozoa were formed, differing from each other by one chromosome. In 1899 Paulmier, working with the squash bug *Anasa tristis,* confirmed Henking's discovery but could not explain its significance. McClung found this same dimorphism of the spermatozoa in the locust *Xiphidium* and named the extra chromosome the "accessory" or "odd" chromosome. In 1902 McClung suggested that this accessory chromosome might have something to do with sex, asserting that the spermatozoa having the extra element probably were male-producing, while those without it might be female-producing. This hypothesis, which really was made in the nature of a mere conjecture, stimulated a large amount of research, and it is with genuine pride that we can point to American biologists as the leaders in this field of investigation.

In 1905 Professor Wilson showed that while there existed a dimorphism of the spermatozoa, yet all of the

ova were of one type and possessed the accessory chromosome. Now, if McClung's contention be correct, Wilson argued, then one should expect to find two accessory chromosomes, in addition to the ordinary chromosomes, called autosomes, in the somatic cells of the male, and only one in the female; but this is exactly the opposite of what he and his students discovered; the female in reality contains the two accessory elements and the male only one. Wilson therefore contended that the spermatozoa with the accessory chromosomes, or X-chromosomes, as he called them, were the female-producing types, while the others were male-producing.

In some species of animals later research established the fact that all of the spermatozoa possessed an extra chromosome, but in one-half of them this was found to be different than in the other half. Professor Wilson called these, respectively, the X and Y chromosomes. All of the eggs, however, carried the X element exclusively. It was further shown that an egg fertilized by a spermatozoön containing an X-chromosome produced a female, whereas one inseminated by a spermatozoön with a Y element gave rise to a male.

The above-established facts may be summarized as follows (N standing for the autosomes, X and Y for the accessory elements):

Case 1.—Where the spermatozoa differ from each other by an X element:

(a) Spermatozoön N+X and Ovum N+X=Zygote NN+XX=Female.

(b) Spermatozoön N and Ovum N+X=Zygote NN+X=Male.

Case 2. — Where spermatozoa each contain an accessory chromosome, X or Y.

(a) Spermatozoön N+X and Ovum N+X=Zygote NN+XX=Female.

(b) Spermatozoön N+Y and Ovum N+X=Zygote NN+XY=Male.

In some animals such as moths and fowls, and perhaps fishes, conditions seem to be reversed. Here the ova are of two kinds, differing from each other by the sex chromosomes, whereas the spermatozoa are all similar, possessing the X element. Therefore, the combinations which yield a male or female also are reversed. In order to distinguish these from the ordinary cases, the X chromosome here is designated as Z and the Y as W, so that a male would have a chromosomal constitution of the formula NN+ZZ and a female either NN+Z or NN+ZW.

In some instances X may be a complex element, consisting of a group of two or more chromosomes all behaving as a single unit. This group occasionally may be accompanied by a single Y element. Furthermore, McClung, Wilson, and others have shown that the sex chromosome may not be distinctly set apart from the other chromosomes, but may be linked to one of the autosomes, making it rather difficult to distinguish it.

Since McClung's famous discovery, sex chromosomes have been found to exist in many invertebrates as well as vertebrates, including man. In plants also, in a few

cases such as the liverworts, sex chromosomes have been established, indicating that sex in plants might also be determined, as in animals, through the medium of a specific combination of chromosomes. In the highest animals, the vertebrates, Guyer was the first investigator to establish the existence of an accessory element. In 1910 he also described a dimorphism in the male germ cells of man, inferring that in all probability sex in man was determined as in the other cases cited, namely, through the medium of accessory chromosomes.

In the past there have been numerous differences of opinion as to whether the number of chromosomes in the white and black races of man is the same, but, in 1923, Dr. Painter, by the use of a perfected technique, succeeded in showing conclusively that there were no chromosomal differences between them, but that there were forty-eight chromosomes within the somatic and immature germ cells of each. His studies also revealed that two types of spermatozoa existed, each containing twenty-four chromosomes, twenty-three autosomes and an accessory one, but that in one-half of them this extra chromosome was the X element, while in the other half it was the Y. Therefore man, as far as sex determination is concerned, belongs under Case 2.

Although the idea of sex determination through a specific chromosome combination is now almost universally accepted, nevertheless during the last few years a number of well-authenticated cases have been reported within the higher organisms, in which the primary, and more particularly the secondary, characteristics accompanying sex have been interfered with,

modified, and even completely reversed. Results such as these have been accomplished, undoubtedly, through the operation of certain internal agencies, either glandular or otherwise, indicating that sex may not be such a simple phenomenon after all, that it may depend for its expression on numerous interacting factors, and that the sex factors within the sex chromosome act, in most cases, as the stimuli which direct the process either toward maleness or toward femaleness. At times, however, the other factors within the ordinary chromosomes may interfere with the sex-determining factors of the X chromosomes so as to modify them considerably, with the result that those secondary or bodily characters which normally accompany one sex may take on the appearance of the other, often making it extremely difficult to distinguish the sex of the individual. In spite of all this, the current opinion is that the sex of an organism is largely established at the time when the gametes join to produce the zygote during the process of fertilization.

5. Methods of Studying Heredity

Heredity is so essential to an understanding of the evolutionary process that the student of evolution must become familiar with the various methods of studying the manner in which traits are handed on from one generation to the next. The history of science reveals that three methods have been utilized for investigating phenomena of inheritance. The first and perhaps the oldest one is that of observation. Here the human eye

exclusively is relied on, and resemblances as well as differences are recorded by an external examination of the organisms dealt with. This method served the ancients and still is used by individuals with little knowledge of the newer developments in the fields of genetics.

The second is the statistical method, and this deals mainly with large numbers or groups of individuals; here an attempt is made to reduce heredity to the mathematical expression of a formula revealing the manner in which each individual in a group resembles or differs from every other individual in it. The statistical method applies mathematical principles and formulæ to the study of problems of heredity, particularly as they concern large numbers of organisms. This method was developed in the latter part of the nineteenth century by Sir Francis Galton (Figure 74), the founder of the modern school of eugenics, and it has been utilized principally by the English geneticist, Karl Pearson, and his co-workers. In recent years the statistical method has grown into a special branch of biology known as biometry, and has proved to be of great value in dealing with large numbers of organisms constituting a population, where an attempt is made to find the average amount of resemblance or difference between the various individuals in the group.

The third and last method of studying heredity is the modern one, and is known as the method of experimental breeding. It has developed largely from the facts established in two fields of study: cell problems, particularly those dealing with maturation and

fertilization of germ cells; and the Mendelian principles of breeding. The relation of the germ cells to heredity has already been indicated. The Mendelian principles have been mentioned, but little has been said regarding them. Since these principles are of vital significance in all modern studies of heredity, it is important that we discuss them at greater length.

6. Mendelism

Mendelism is the name applied to the method of experimental breeding which has been in vogue since 1900. It is based largely on an analysis of the specific characteristics with which one is dealing, for the purpose of discovering the manner in which they behave in crossing. Prior to 1900 genetics hardly could be called an experimental science, since all of the deductions were based largely on observation and a slight application of the statistical method. Of course, biologists knew that heredity and variation were potent factors in the production of offspring, but they had no method of measuring, quantitatively and qualitatively, the manner in which these factors operated in producing the results obtained. The real difficulty lay in the fact that geneticists attempted to deal with all of the characteristics of an organism instead of with just a few of them, so that it was impossible to predict how even the simplest character would behave in crossing. Since 1900, however, more progress has been made in the field of genetics, in the study of heredity and variation, and in problems of breeding both plants and

animals, than in all of the centuries since the dawn of civilization. Genetics has progressed until it is now almost an exact science, in some instances nearly as exact as the science of mathematics, making it possible for geneticists to predict many definite results and conclusions applicable to numerous representatives of the plant and animal worlds. The geneticist of today is no longer working in the dark; knowing how the germinal entities responsible for characters behave in crosses, he is now able to plan experiments for the purpose of producing new types, showing combinations of desirable characteristics, as well as the elimination of undesirable ones. Mendelism, or experimental breeding, has made this possible, and at the same time has revolutionized all of the old conceptions of genetics.

The word Mendelism is derived from the author of the principles, Johann Gregor Mendel (Figure 55), an Austrian monk who was born in 1822 and died in 1884. While Mendel was abbot of the monastery at Brünn, Austria, he experimented with the common variety of garden peas in the cloister gardens. His main experiments were conducted between the years 1857 and 1868, during which time he discovered the important principles of breeding which bear his name. In 1865 he published the results of his experiments in an obscure Austrian journal known as the *Proceedings of the Natural History Society of Brünn*. This was a purely local scientific magazine with a very limited circulation; and since very few people outside of the immediate vicinity of Brünn were acquainted with it, Mendel's findings were lost to the scientific world for

a long time. It is interesting to know that Mendel, before he published his paper, sent a copy of it to his old teacher, Carl von Nägeli, professor at the University of Vienna, but for some unknown reason Nägeli completely ignored it, so that the Mendelian principles remained unrecognized for many years.

In 1900 they were re-discovered through the efforts of three biologists — Correns of Germany, Tschermak of Austria, and De Vries of Holland. These men, working independently in different countries, without knowledge of each other's research or of Mendel's previous accomplishments, almost simultaneously hit upon the same conclusions. In tracing the previous literature on the subject, they accidentally came across Mendel's contribution, and were magnanimous enough to give him credit for his work by applying the name "Mendelism" to the principles which they had independently discovered.

Mendel studied simple hereditary phenomena, dealing with single traits that behaved as distinct entities in heredity, and from them he derived definite laws which opened up a new vista of discoveries. Since 1900 scholars have enlarged considerably upon Mendel's views, and also have changed their opinions regarding some of them. Fundamentally, however, Mendel's work has been found to be sound, and upon it, as a foundation, rests the newer genetics of the present era.

Before examining the Mendelian principles more closely, we may consider the reason why the scientific world failed to recognize Mendel's discoveries when he published them. In the years 1858 and 1859 the whole

world was startled by the evolutionary enunciations of Darwin and Wallace. *The Origin of Species,* it will be remembered, was published in 1859, and for fifteen years after its appearance the intellectual world was engaged in controversy over the validity of its contentions. In reality, scientists were too engrossed with the Darwinian theory to bother about any other principles, so that it is not astonishing that Professor Nägeli, when he received Mendel's paper, either put it aside, never to read it, or, if he read it at all, was in all probability too busy to recognize its merit.

The essential features of Mendelism are embraced in the so-called Mendelian Law, which can be interpreted in the following manner: When organisms that differ with respect to a trait are crossed, the resulting progeny invariably will resemble one of the parents. The parent organism that stamps its character on the offspring is known as the dominant one, and the character which it impresses is spoken of as the dominant character. The other organism which enters into the cross is termed the recessive parent, and the non-appearing character which it transmits is called recessive. When, in turn, the first generation hybrids are crossed with each other, they give origin to a mixed progeny, one-fourth of which are pure dominants, one-fourth pure recessives, and one-half hybrids — the latter, however, resembling the pure dominant type, so that in the second generation the offspring obtained outwardly appear as three-fourths dominant and one-fourth recessive. In some other crosses made since Mendel's time, the hybrid offspring have been found

to differ from the parents in appearance, so that in the second generation offspring the pure Mendelian ratio of one-fourth dominant, one-fourth recessive, and one-half hybrid has been obtained. Essentially, Mendel's law may be said to regard hereditary traits as independent units which separate out upon crossing, irrespective of temporary dominance in the hybrid offspring. Mendel's law, coupled with its essential features, is the basis for all present-day experimental breeding, and it links up very nicely with the various facts gained from the study of the cellular basis of heredity.

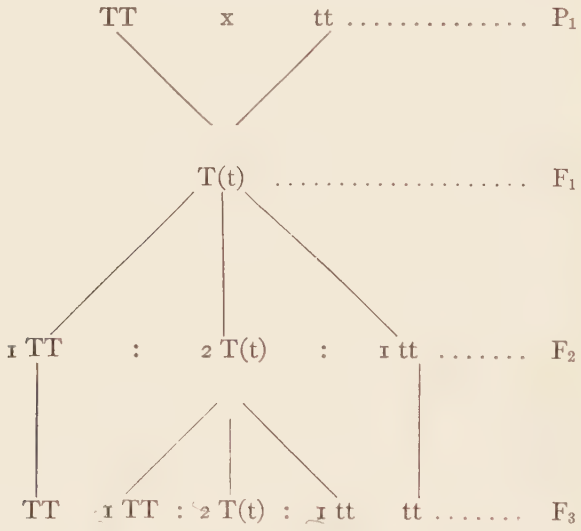
In connection with Mendelism a distinct terminology has developed, and we must have a clear understanding of this before we can proceed with the further analysis of the principles. The individuals or parents used in crosses are designated by the capital letter P; the immediate parents are indicated as P_1, the grandparents as P_2, the great-grandparents as P_3. The progeny are represented by the capital letter F; the first generation offspring as F_1, the second generation as F_2, and so on. The unit traits in the parents entering the cross also are indicated by letters, dominant traits by capital letters, and these in every instance are the first letters of the traits dealt with. The recessive characters are represented by small letters of the ones used to indicate the dominant traits. It must also be emphasized that in representing an individual used in a Mendelian cross, consideration is given only to those traits for which the cross is made. For instance, the tall plants used by Mendel are represented by the letters TT, and the

dwarf plants by tt, whereas all of the other traits which comprise these organisms are, of necessity, omitted; for to represent them would so complicate heredity as to produce a hopeless confusion. The fact must not be forgotten that every higher organism really is a combination of a very large number of heritable traits; in Mendelism, however, the best we can hope to do is to deal with an insignificant number of them at one time. Where one trait is considered in breeding, the cross is spoken of as a monohybrid; where two, three, or more are dealt with, the crosses in question are called, respectively, dihybrids, trihybrids, etc.

All of the crosses which follow will be expressed in accordance with the Mendelian terminology as explained. The organism, since it is produced by the combination of two germ cells, representing a double set of characters, will be indicated by double letters for every character involved. The germ cells of the individuals which really combine in crossing will be designated by single letters for every character in question.

One of the first breeding tests performed by Mendel was to cross a tall strain of the garden pea, *Pisum sativum*, with a dwarf strain, and in the first generation all of the plants were impure, or hybrid talls, which looked exactly like the original tall parents. When the hybrid talls were interbred, the resulting offspring showed that three-fourths of them were tall individuals and one-fourth dwarfs. When a further analysis of this ratio was made through the method of saving seeds of each plant obtained in the second generation and planting them in the following spring, it was shown that of

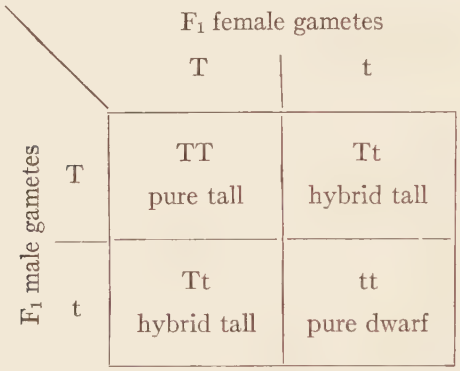
the three-fourths tall plants, one-fourth really were pure talls, while the other two-fourths were hybrids, which produced in the third generation the ratio of three-fourths tall and one-fourth dwarf plants. Based on such an analysis, the ratio of individuals produced in the second generation may be written: 1 pure tall: 2 hybrid talls: 1 pure dwarf. The following illustration shows results expressed in current Mendelian terminology:



It has been stated that Mendelian breeding work bears out exactly what, for a long time, has been suspected to occur during the maturation of the germ cells, namely, the segregation of the entities responsible for the unit characters derived from the father and the mother. This can be seen more clearly when the above-

mentioned Mendelian cross is considered in terms of unit characters. Since the tall peas (TT) are pure for the character of tallness, then all of the gametes produced by them can bear only the determiner for tallness, T. Similarly, the dwarf plants (tt), since they are pure, can develop only gametes bearing the entities for dwarfness, t. Now, when a gamete carrying the tall-character determiner meets one carrying the determiner for dwarfness, the result is a hybrid plant T(t) possessing the potentialities for both tallness and dwarfness. However, the gametes of this hybrid can carry only one factor for the height character, and, as experiment bears out, fifty per cent of the germ cells produced bear the determiners for the tall characteristic, while the other fifty per cent bear those for the dwarf characteristic. The male hybrid, as well as the female hybrid, produces these two types of gametes in equal numbers. When fertilization occurs, the resultant possible crosses are; (A) a tall spermatozoön fertilizing a tall egg, giving a pure tall individual, TT; (B) a tall spermatozoön fertilizing a dwarf egg, giving a hybrid tall carrying dwarf characteristics, T(t); (C) a dwarf spermatozoön fertilizing a tall egg, giving a hybrid tall carrying dwarf characteristics, T(t); and (D) a dwarf spermatozoön fertilizing a dwarf egg, producing a pure dwarf, tt. Summarizing all of the possibilities, we get the following ratio of individuals, 1 TT: 2 T(t): 1 tt. The diagram which follows shows the gametes produced by the F_1 individuals and the resultant F_2 products. Incidentally, it also indicates a convenient way of schematically

arriving at Mendelian results where one or more factors may be involved.



Mendel made many other similar crosses for different characteristics in plants, and all produced similar results. Since his time, the animal breeder has shown that the same things hold true in his field of experimentation. In the case of the blue Andalusian fowl, the Mendelian principles work out very nicely. Poultrymen know three kinds of Andalusian fowl, the black (BB), the white (WW), and the blue (BW). When they mate black ones, their only results are black fowl; when white ones are crossed, only white fowl result. However, when a black Andalusian fowl is mated with a white one, then all of the offspring are blue. The hybrid here differs from both of the parents so that it can be readily distinguished from them. When, in turn, the blue fowl of the first generation are mated, the offspring of the second generation show the typical Mendelian ratio of 25 per cent blacks, 50 per cent blues,

and 25 per cent whites. The blacks always produce blacks, and the whites also breed true; but the blues never produce more than 50 per cent blues, the other 50 per cent being divided equally between the blacks and whites. The chart below and Figure 64 show the various details of the cross mentioned.

This cross brings out still another principle in Mendelism, namely, the interaction of factors. Mendel thought that a single factor was always responsible for a single character, known as a unit character. We are now aware that many characters depend for their expression on the interaction of two or more factors. The character of blue color here depends on the presence in the same individual of the two factors for whiteness and blackness. If either the one or the other is missing, then the blue does not make its appearance.

Mendel also studied the behavior of two characters in crosses, and while the same essential principles held good for them as for a single character, except that they were a little more complicated, nevertheless he established the further fact that a new combination of

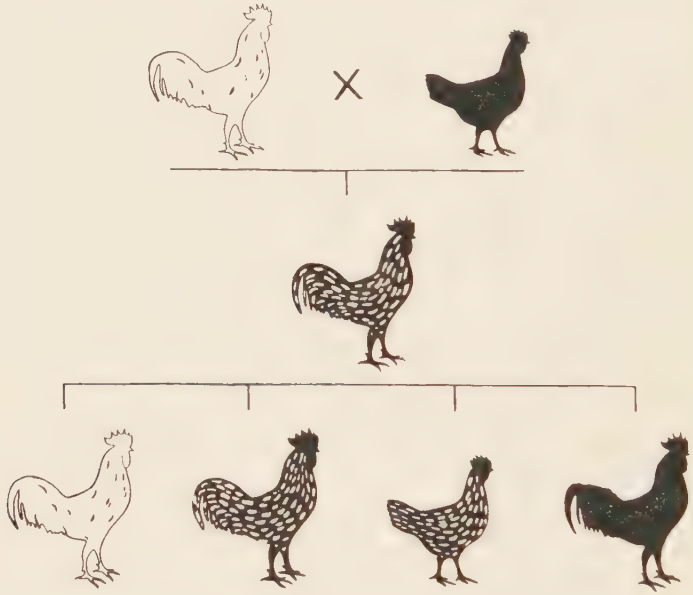


FIG. 64. CROSS BETWEEN WHITE AND BLACK ANDALUSIAN FOWL
The resulting blues are represented by black figures with white splotches.

characters could be brought about, resulting in new types of individuals. A typical case will illustrate this principle. Mendel crossed a variety of pea having round, yellow seeds (RRYY) with one possessing wrinkled, green seeds (rryy). In the first generation all

of the offspring bore seeds that were round and yellow (RrYy). When these were interbred in the second generation, the progeny consisted of the ratio of 9 round yellow: 3 round green: 3 wrinkled yellow: 1 wrinkled green. An examination reveals that a new

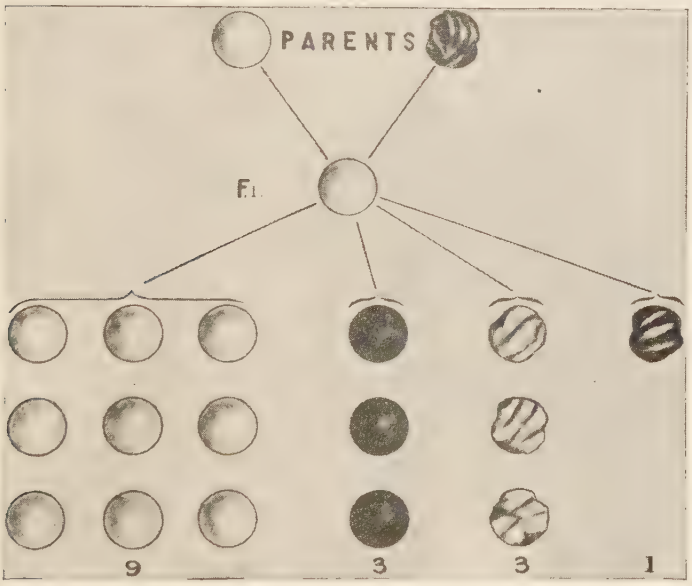


Fig. 65. Cross Between Peas

The species represented are the round yellow and the green wrinkled peas. (From Morgan, *Evolution and Genetics*. Courtesy of Princeton University Press.)

combination of characters had taken place, namely, round green individuals and yellow wrinkled ones. Figure 65 shows the results of such a cross.

In the case of animals similar crosses have been

made, with identically the same results as in the case of peas. One of the most interesting of these experiments, made by Professor Bateson, the English geneticist who died a short time ago, involved the combs of fowls. The combs may be of various kinds, such as rose, pea, single, or walnut. When rose-, pea-, or single-combed fowls are each mated with similar types of individuals, they are found to breed true, the progeny bearing combs like the parents. In cases where rose-combed individuals are crossed with single-combed, all of the offspring are rose-combed. When pea-combed individuals are crossed with single-combed, the progeny are all pea-combed. This indicates that the rose- and pea-combed characteristics are dominant to the single-combed. On the other hand, when rose- and pea-combed fowls are crossed, instead of one dominating the other, a new type of combed fowl is developed, bearing the so-called walnut comb. When these walnut-combed individuals of the F_1 generation are mated, they produce the following types of combed individuals: 9 walnut-: 3 rose-: 3 pea-: 1 single-. This, of course, is the ratio for a dihybrid, similar to the ratio obtained in the cross of the round yellow peas and the wrinkled green ones. Professor Bateson's experiment becomes intelligible if we represent the rose-comb characteristic by R, and the one for pea-comb by P. Then the germinal constitution of the rose-combed parent is RRpp, and for the pea-combed one rrPP. When these individuals are crossed, we get the factors R and P combined in the constitution of the F_1 individuals, RrPp, and this gives the walnut-combed fowls. When both R and P are

lacking, as in an individual of constitution rrpp, we get the single-combed type. Walnut, therefore, depends on the presence of both dominant characters, R and P; single depends on their absence. Individuals with the constitution Rrpp are rose-combed, while those of constitution rrPp are pea-combed. Figure 66 shows the

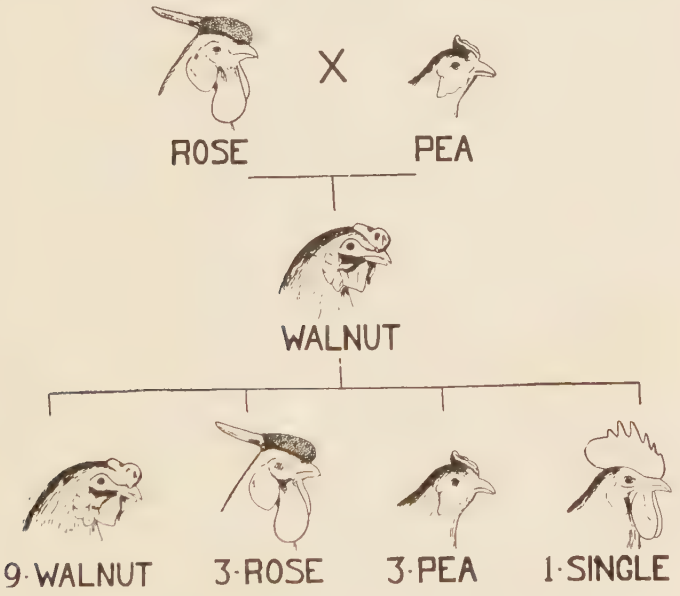


Fig. 66. Cross Between Rose- and Pea-combed Fowl

types produced. This cross, like the one on Andalusian fowls, indicates that Mendelian phenomena often are much more complicated than was at first supposed. In many instances characters depend for their expression on the presence or interaction of two or more entities within the individual.

Crosses involving three and more factors have also been made, and while they are more complicated, nevertheless the same principles hold good for them. One can easily imagine how useful such breeding may become from a practical standpoint, particularly where undesirable and desirable traits are found in different individuals which lend themselves to free crossing. By wise manipulation and direction the desirable traits of both may perhaps be concentrated into one individual, and at the same time the undesirable ones may be entirely eliminated, making possible improvements of great benefit to industry, commerce, and humanity. Such results actually have been accomplished since 1900 through the application of the laws in question.

In recent years the Mendelian principles have been enlarged by the discovery of the so-called "linkage groups" and "crossing-over" phenomena. These have complicated matters considerably, but far from weakening Mendelism they have lent additional strength to it. In order to illustrate linkage phenomena of inheritance, a single case of sex-linked inheritance will be discussed. The question of sex determination through specific chromosomes has already been considered. Aside from being sex determiners, the accessory chromosomes in the human individual may also be the carriers of certain sex-linked characters, such as color-blindness.

Color-blindness is transmitted from a color-blind father through his daughters to one-half their sons (Figure 67). This is due to the fact that the factor for color-blindness is carried within the X or sex chromosome, so that a single dose of it is required to produce a

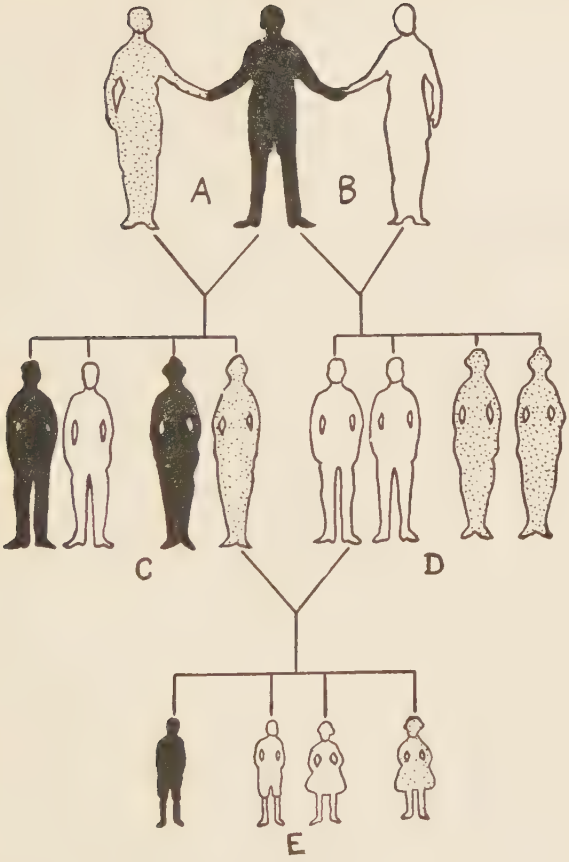


FIG. 67. SEX-LINKED INHERITANCE OF COLOR-BLINDNESS

The black figures represent individuals who are color-blind; the shaded figures represent "carriers," those in whom the trait is covered over; the white figures represent normal individuals. A represents a cross between a color-blind male and a carrier female, with the resultant progeny seen in C. B represents the union of a color-blind male and a normal female, with the offspring indicated in D. E represents the progeny of the mating of a normal male with a carrier female.

color-blind male, and a double dose a color-blind female. In cases of females, where only one X carries the color-blind factor, no color-blindness makes its appearance, but one-half of the sex cells of these individuals carry the trait and may be responsible for the character in the later offspring. Figure 68 shows a cross between a normal female and a color-blind male, expressed in terms of the sex chromosomes only, and it becomes clear if it is remembered that in humans the male has the XY combination and the female the XX. In the figure, the light X represents the sex chromosome that carries the factor for color-blindness, while the dark X is the normal one. In the first generation, all of the females produced show no color-blindness but are carriers of the factor for the trait; the males are all normal. The second generation offspring, or those from a mating of a mother carrying the color-blind factor with a normal father, produces a ratio of 25 per cent normal daughters, 25 per cent daughters who are carriers for color-blindness, 25 per cent normal sons, and 25 per cent color-blind sons. This is also shown in Figure 67 E. Sometimes color-blind females may be produced, and this is caused through the mating of a color-blind male with a female who is a carrier for the factor. Such a cross, with its resultant progeny, is seen in Figures 67 A and 67 C.

Professor Morgan and his students have shown, in the fruit fly *Drosophila*, that all of the chromosomes, the sex chromosomes as well as the ordinary ones, may be the possessors of numerous linked hereditary elements — the genes, as Professor Morgan calls them —

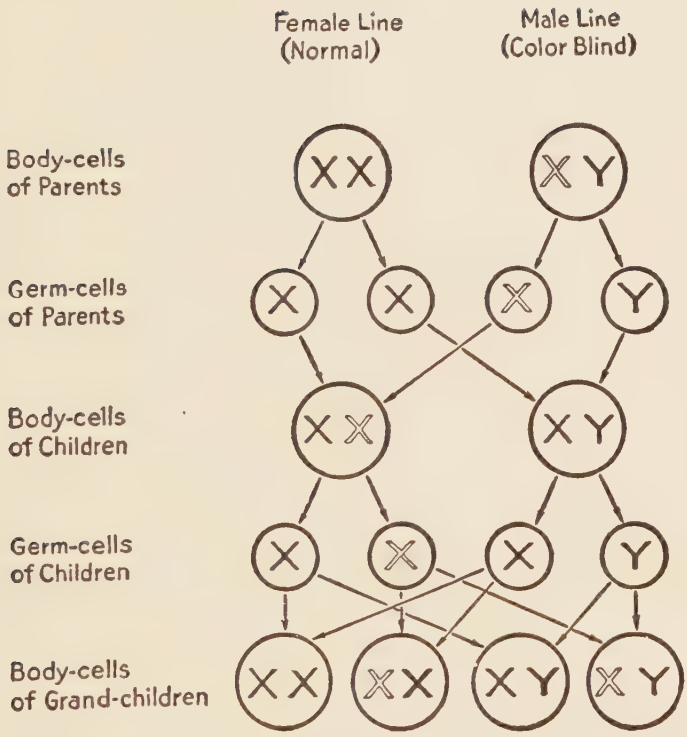


FIG. 68. RÔLE OF THE X-CHROMOSOMES IN TRANSMITTING COLOR-BLINDNESS

The black X represents the normal chromosome; the white X represents the chromosome carrying the factor of color-blindness. (From Guyer, *Being Well Born*, Copyright 1927. Used by special permission of the publishers, the Bobbs-Merrill Company.)

which are the germinal representatives for characters appearing in the individuals. In the study of linkage it has been deduced that the determiners for characters probably are linked within the chromosomes like a series of beads in a beaded chain. Each chromosome really must be looked upon as having a distinctive group of determiners which differ from those found in every other chromosome of the germ cell. In most cases these groups remain linked together, but occasionally some of them may become separated and new expressions may result in the offspring. The study of the maturation phenomena of germ cells has given us a clue as to how the segregation of these linked factors might be accomplished. In some organisms it has been discovered that during certain phases of the growth period, the pairs of homologous chromosomes derived from opposite parents twist around each other (Figure 62), so that when the reduction division occurs each chromosome, instead of being the original entity that it was, really consists of a combination of representative portions from the homologous pair, that is, of some genes from the father's side and the remainder from the mother's. Little more need be said regarding these complicated phenomena of heredity, since additional information on the subject is to be found in any good textbook on genetics. For our purposes, the important point is that an understanding of these phenomena helps to account for the evolution of some varieties and species.

Before this portion of the discussion is closed, the fact must be emphasized that the experimental in-

vestigation of heredity, through Mendelism, has borne out in striking manner what has been established through cytological research, namely, that the germ cells are wonderfully constructed units possessing the potentialities for producing the characteristics of the organisms which ultimately develop from them. Each germ cell must be looked upon as a remarkable mechanism consisting of a unique organization with tremendous powers of assimilation, growth, and development. Until very recently this cellular organization was regarded as predetermined, as being composed of minute particles similar to the so-called "ids" of Weismann's theory, representing the characteristics of the adult organism. This, of course, is more or less of a preformation point of view. Of late, however, this idea has been changing gradually, and the emphasis now is being placed on the chemical organization of the germ cell rather than on its particulate organization. Many biologists are in full accord with Professor Wilson when he says:

> The whole tendency of modern investigation has been towards a different and more rational conception which recognizes the fact that the egg is a reaction-system and that the whole germinal complex is directly involved in the production of every character. Genetic research is constantly bringing to light new cases of the coöperation of several or many factors in the production of single characters; and it is possible that all of the chromosomes, or even all of the units which they contain, may be concerned in the production of every character. Beyond this it is evident that every character is produced during development by an activity in

the cytoplasm, and what we call the " organism as a whole " plays a most important part. When, for example, we speak of the X-chromosome as a " determiner " of sex, we mean only that it is a differential factor or modifier the relative quantity of which in relation to the autosomal material conditions a particular reaction by the developing germ. The value of the chromosome-theory of heredity does not lie in our identification of this or that " determiner " or " bearer of heredity," but in its practical importance as a means of experimental analysis. In this respect, in the writer's opinion, the theory has the same kind of value as the molecular and atomic constructions of physico-chemical science; and the " mystical," and " unscientific " character ascribed to it by some writers is purely imaginary.[5]

7. Variation

Variation is encountered universally in all nature. It is of such obvious occurrence in organisms that nearly everyone unconsciously picks out the differences even more readily than the resemblances. The variations which crop out in individuals related by descent make possible different expressions, thereby laying the foundation for the evolution of new forms.

In the main, two classes of variations have been recognized by biologists. The first includes the fluctuating or continuous variations, those which invariably are so small and slight that often it is difficult to distinguish them from the basic traits which gave origin

[5] *The Cell in Development and Inheritance,* 3d. ed. rev., p. 976. Copyright 1925 by The Macmillan Co. Reprinted by permission of the publishers.

to them. Charles Darwin emphasized these modifications, above all others, as of greatest significance in his scheme of evolution. In his opinion, while these variations might not produce anything radically different in a short period of time, even in an interval as long as that embraced in the normal span of human existence, nevertheless if they were allowed to run on for a much longer period, the results would accumulate to such an extent that in the end a distinctive new variety and ultimately a species would be produced. On such a basis Darwin accounted for the origin of most of the species.

Darwin made no attempt to analyze critically his fluctuating or continuous variations. He considered them as actual transformations which originated either within the germinal material or within the body of organisms. In both instances, the changes gained expression only if they were of utility. The germinal modifications appeared directly in the immediate offspring, whereas the bodily transformations, before they could be inherited, first had to become incorporated into the germinal stream of the parents, through the agency of pangens. Since Darwin's time, geneticists have carefully investigated the capacity of these small, continuous or fluctuating variations to produce anything really new, and have come to the conclusion that they are ineffectual in this direction. Therefore, these modifications now are looked upon as merely somatic changes, dependent for their expression solely on environmental influences, and incapable of yielding any new varieties or species.

The second class of variations comprises those which are germinal in origin, appearing suddenly, and designated variously as discontinuous variations, saltations, sports, or mutations. They may be large or small modifications in animals and plants which arise suddenly and discontinuously; and, what is even more important from an evolutionary standpoint, they are heritable. In recent years these differences have been stressed by students of evolution as being the most potent ones in the production of new species. This has come about chiefly as a result of the work of the Dutch botanist, Hugo De Vries, who discovered several new types originating in this manner among the evening primroses which grew wild in an uncultivated field near his laboratory. Since De Vries' emphasis on mutations, many biologists have been inclined to regard them as the exclusive means of bringing about the origin of new species. Darwin, as will be recalled, also recognized discontinuous variations as agents in evolution, for in his *Origin of Species* he distinctly points out quite a few new creations which have come into existence through their operation. He regarded them, however, as of secondary importance to the continuous or fluctuating kinds, the ones which in his estimation were the most potent as well as the most common variations that brought about the origin of species.

In this connection, it must be indicated that Darwin considered a mutation a very prominent variation, standing out so strikingly as to be distinguished very easily. At present, however, mutations are regarded as large or small modifications, originating germinally

and discontinuously. They are the true germinal changes which form the basis for the evolution of varieties and species.

Although the fact of variation is quite obvious to everybody, the causes which bring it about are as yet little understood. One of the oldest attempts to account for variation holds that it is a response to the environment in which forms dwell. This conception regards the living organism as a piece of plastic material which is made to fit its environmental mold. The mold or environment may be said to shape the destiny of the organism. It is true that the environment, in a way, forces living things to adapt themselves to various conditions, but it is a debated question whether bodily changes induced thereby are permanent; and even if they were permanent, the question of how they could be incorporated into the hereditary germinal make-up of an organism still would remain unsolved.

Another explanation, and also an ancient one, was developed by Lamarck and his contemporaries, and is embodied in the principle of use and disuse of structures. According to this principle, the use of a bodily structure or organ exercises it, thereby making it more efficient and at the same time causing it to vary in a positive direction. Likewise, the disuse of a bodily portion causes it to remain idle, and consequently to undergo degenerative changes which bring about its atrophy, so that the structure may be said to vary in a negative direction. In either case, the assumption is that bodily changes are induced which will be transmitted from generation to generation, until pronounced

variations in one or the other direction take place, with the result that new species will ultimately originate. Here again, however, there is a big question whether bodily changes such as those induced through use and disuse of special parts can be incorporated into the hereditary constitution of an organism.

The third explanation of the cause of variation is the result of Weismann's enunciation of the germ-plasm principle. According to the Weismannians, variation may be caused in one of two ways: first, either it originates spontaneously within the germ-plasm, or second, it results from the admixture of hereditary traits brought in by opposite germ cells during the process of fertilization. The first explanation does not answer the question at all. It is true that the germ-plasm may vary spontaneously, but what causes it to do so? The second explanation, called technically by Weismann the principle of amphimixis, attempts to solve the problem a little more satisfactorily, but under careful examination it also is found to be inadequate. Essentially, amphimixis tells us that when two streams of germ-plasm from opposite parents come together in the process of fertilization, the various determiners for characteristics brought in undergo a struggle, and influence one another to such an extent that some of them either gain ascendancy or become modified so as to appear as new expressions. In our study of the Mendelian principles of breeding we saw that quite often new combinations of factors occurred, resulting in apparently new types, and that these could be interpreted as distinct variations, were it not for the fact

that breeding tests showed them to be due to nothing more than a realignment of genes already existing in the germinal constitutions of the parental stocks. The results are due merely to a shuffling and recombination of determiners, making possible the expression of some which previously were submerged. Of course, we know that on occasion new factors do make their appearance, bringing into existence new variations. Here again, however, the causes which produced the results, accounting definitely for the emergence of the modifications, are not explained.

The fourth and last explanation for the origin of variation is that of parallel-induction, developed principally in the last few years. The biologists belonging to this school often are called Neo-Lamarckians or, more accurately, Parallel-Inductionists. They have sought to produce conclusive evidence that instances of inheritance of acquired bodily modifications are common in nature and play an important *rôle,* if not the only one, in evolution. The ideas of the Parallel-Inductionists may be outlined briefly as follows: when a stimulus, either external or internal, acts upon a bodily structure so as to change it in a definite direction, it might at the same time also engender within the interior protoplasmic constitution of the organism a certain something, chemical or otherwise, which, when it comes in contact with the germinal determiners for the characteristics in question, causes them to become modified in a similar direction. Some stimuli might not evoke sufficient internal response to produce a parallel modification of the germinal entities responsible for the

somatic expressions involved, and in such cases no visible effects would be produced in the offspring. In other instances, stimuli acting over long periods of time, while they might bring about marked visible changes in bodily structures during the normal lifetime of the organism concerned, might also, during this same period, induce parallel changes within the germ-plasm so slight as to be scarcely discernible in each of the following generations; but in the course of time, as the modifications persist in generation after generation, they could accumulate slowly, definitely, and persistently within the germ-plasm so as eventually to bring about a decided change within the species.

While numerous attempts have been made in this direction, practically all of them negative or inconclusive, nevertheless the experiments which have shed most light on the parallel-induction point of view are those on rabbits, conducted during the past few years by Drs. Guyer and Smith at the University of Wisconsin. These researchers availed themselves of the knowledge gained from the study of serology and immunity reactions of organisms in a new attack on the age-old question of the inheritance of acquired modifications. It has been a well-known fact, developed in the fields of both serology and immunity, that the blood of an organism, when invaded by some foreign structure or organism, will build up a certain something — let us call it a chemical agent — which enables the attacked organism to fight off and destroy the invading object or organism. Further, it has been established that this acquired modification in the blood stream or

circulating sap occasionally can be passed on to the offspring, for a few generations, so that they also possess the same characteristic as the original parents. Drs. Guyer and Smith, taking cognizance of these well-established facts, wondered whether through the use of pulped bodily structures they could induce the blood stream of an organism to build up agents which would bring about modifications, not only in the specific adult tissues corresponding to those used for injection purposes, but also within the germinal determiners responsible for their expression.

This is exactly what the Wisconsin investigators have accomplished. They chose rabbits for their experiments and singled out the lens of the eye for modification. By injecting pulped lenses from the eyes of rabbits into pregnant females, they were able to bring about defects in the eyes of some of the offspring, and without any further treatment the induced modifications appeared in later generations with no discernible diminution in intensity. The changes produced showed themselves so clearly that anyone could recognize them. The eyes, instead of being normal, were either dwarfed, or cloudy or liquefied. Figure 69, taken from one of the published papers of Drs. Guyer and Smith, show the results obtained.[6] It was also shown that males derived from the defective strains, whether or not they showed the modifications, when bred to normal untreated females produced in later

[6] "Studies on Cytolysins. II. Transmission of Induced Eye Defects," *Journal of Experimental Zoölogy*, vol. 31 (1920), pp. 171–223.

generations some defective offspring. In other experiments,[7] the lenses of rabbits' eyes were directly injured by a needling process, and when the animals were bred some of their offspring showed the same eye defects as those coming from parents treated with pulped lens injections. This seems to indicate that on occasion a

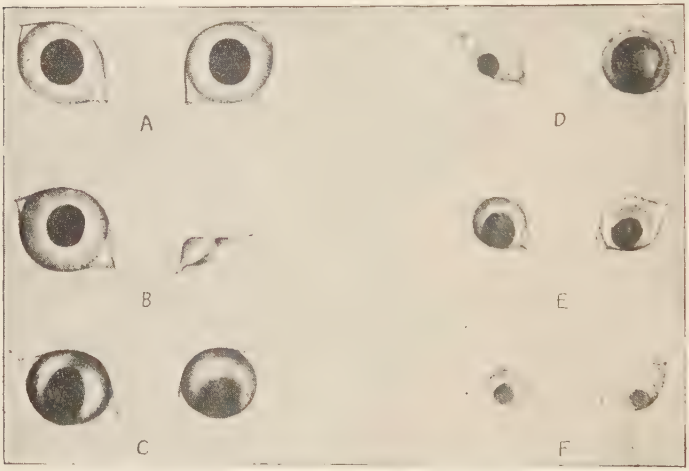


Fig. 69. Normal and Defective Eyes in Rabbits

A, normal pair of eyes; B–F, pairs of eyes showing induced defects. (After Guyer and Smith. Courtesy of *The Journal of Experimental Zoölogy*.)

modified somatic structure may be the means of inducing changes within the blood stream of an organism, which influence the germinal factors responsible for the expression of the character in question, and cause them to alter in a somewhat similar direction. In all of these

[7] Guyer, M. F., *Being Well Born*, 2nd. ed. rev., Indianapolis, Bobbs, Merrill, 1927, pp. 277–278.

cases, the eye defect appears to behave like a Mendelian recessive, coming out in about twenty-five per cent of the offspring.

In the final analysis, the problem of the evolution of species revolves around the question of the origin of variations and their incorporation into the hereditary mechanism of the germ cells responsible for offspring. While many geneticists still believe that no acquired modifications can ever be inherited, yet during the last few years the number who are of a different opinion has been growing steadily, and they are in full accord with Guyer when he asserts:

> May we not surmise then that as regards inheritance and evolution, Lamarck was not wholly in error when he stressed the importance of use and disuse of a part, or of modifications due to environmental change, in altering the course of the hereditary stream, particularly if we conceive of these influences as being prolonged, possibly over many generations? Have we not in the serological mechanism of the body of animals an adequate means for the incitement of the germinal changes which underly certain aspects of evolution? [8]

[8] "Immune Sera and Certain Biological Problems," *American Naturalist,* vol. 55 (1921), pp. 97–115.

CHAPTER XII

CAUSAL FACTORS OF EVOLUTION

The factors which account for evolution have been dealt with to some extent in the preceding chapter. At the present time there is considerable disagreement among scientists concerning the process or processes which have brought it about. Science in general is solidly behind the fact of evolution, but concerning the manner in which the phenomenon has been engendered there are marked differences of opinion. The dilemma is somewhat similar to that which faces the biologist in dealing with the question of life. All of us know what is meant by life and living matter in general, but when we attempt to define life or what actually causes it, we encounter a seemingly impenetrable mystery. The various hypotheses which have been formulated to account for the origin of species were discussed briefly under the historical survey of evolutionary thought. As was outlined there, five concrete theories have been offered in explanation of the evolutionary process. It is now important to reconsider them more critically and in logical sequence.

The first conception is that propounded by the great French naturalist Lamarck, and already has been alluded to as the Lamarckian principle of evolution. It is based largely on the assumption of the operation of

factors, engendered through the use and disuse of organs, resulting from stimuli of either an internal or an external sort. As will be recalled from foregoing discussions, the use of an organ emphasizes it, so that it becomes not only a more stabilized and efficient structure, but also one that tends to vary in the direction of greater utility. Furthermore, the development of the resulting modifications, if they run over a long period of time, leads to the gradual production of something different, ultimately bringing about the creation of a new variety or species. The factor of disuse operates in the opposite direction, effecting modifications in organs or structures which may be responsible for profound changes in species. The various vestigial structures in organisms can be accounted for on the basis of this principle in operation. The disuse of a portion results either from the failure to operate of a stimulus which was originally responsible for the development of the structure concerned, or from a change in the behavior of the organism, a change which stresses structures of the body other than the one in question. The net result of all this brings about the degeneration and atrophy of the disused portion, so that in time it loses its ability to function normally. Lamarck's principle of evolution postulated the acquisition by organisms of bodily modifications which somehow became incorporated into the hereditary mechanism of their reproductive cells and thereby were transmitted to offspring.

In regard to this matter, it was pointed out previously that, as the result of Weismann's experiments, the

inheritance of acquired characteristics appeared to be a myth. Therefore the biological world of that period condemned the Lamarckian viewpoint, stating that only those determiners for characters which either were a part of the material of the germ cells or originated within it, could make their appearance in offspring and play any *rôle* in furthering evolution. It was also indicated in the discussion of variation in the chapter on the basic factors of evolution, that during recent years quite a few biologists have put themselves definitely on record as Neo-Lamarckians, or Parallel-Inductionists, firmly believing that certain bodily modifications may, on occasion, influence the germinal determiners of the bodily structures concerned, so as to cause them to change in a like direction, thereby making possible some degree of evolution.

The second causal explanation for evolution is the one enunciated by Charles Darwin in his monumental volume *The Origin of Species*. Darwin, from his extensive travel and study, realized that many varieties and species of plants and animals were produced by breeders through careful and rigid selection. For instance, all of the various breeds of pigeons were derived from the single wild species, the European rock-dove *Columba livia*. The numerous types of fowls have originated from the wild species of red jungle-fowl *Gallus gallus*, found in certain regions of the Orient. Beebe, in his work on pheasants, remarks:

> Of all the pheasants, indeed, of all birds in the world, the Red Jungle-fowl stands first in importance to mankind on the earth. From this species, and this alone, all the forms of

domestic fowls have taken their origin, and hence from this relation to man of economic utility this bird assumes a position of great interest.[1]

Likewise, the various types of cats, dogs, horses, pigs, and other domesticated animals, as well as cultivated plants, have been produced. In all of these instances, the breeder simply took advantage of minute differences which presented themselves, and he inbred those which struck his fancy, so that they not only became accentuated, but led ultimately to the establishment of new types, varieties, or species.

Darwin, aware of this fact, argues that, since such selection has been responsible for evolution under the artificial guidance of man, why is it not logical to assume that a somewhat similar process holds good for species in the natural state? His careful and extensive studies of animals and plants firmly convinced him of the validity of his conclusion. He came to the realization that Mother Nature was a blind, potent force, selecting for perpetuation those individuals who possessed variations which enabled them to cope efficiently with the conditions of the environment, and at the same time eliminating those who were handicapped in their ability to meet the exigencies of the struggle for existence. Darwin believed that in most instances the modifications which fitted or unfitted an individual were so small that the average person would fail to recognize them; but he insisted that, from the standpoint of evolution, they were extremely important in

[1] *Pheasants: Their Lives and Homes,* New York, Doubleday, Page, 1926, vol. 1, p. 196. Reproduced by permission of Mr. Beebe.

determining survival or extinction of species. He also knew of the larger, discontinuous variations that appeared suddenly and were so distinctly marked off from the organisms which gave origin to them that they could very readily be recognized. These were, of course, the sudden variations, sports, or saltations, or, as we now call them, mutations; and while Darwin showed how they might be important in the origin of species, he nevertheless considered them of less significance in evolution than the small, fluctuating, or continuous ones.

The essential fact to be emphasized in considering Darwin's plan is that, in large measure, he took for granted the inheritance of acquired modifications, and stressed the minute, fluctuating variations exhibited by organisms as being of greatest importance in the process of evolution. It is true that he mentioned mutations, but he accorded them but slight value in the origin of species. Since Darwin's time, and particularly since the enunciation of De Vries' mutation conception, many investigators have critically examined the *rôle* played by the small, fluctuating variations in the production of new species, and all of them, with a few exceptions, have concluded that such modifications do not operate in bringing about permanent changes in type. They believe that these fluctuations are merely the outward expressions of the general possibilities which happen to be inherent within the germ-plasm of the type concerned, brought out or selected under the stimulus of some specific influence or influences of a certain environment. However, as far as producing

something new is concerned, no amount of selection of such variations can bring about a change that will yield a new species.

During the last few years many experiments have been conducted to test whether selection of continuous variations can produce anything new; but without discussing them in detail, we may say that they have not been effective in this direction. The most helpful experiments have been those which have dealt with selection within so-called pure lines. The term "pure line" is used to denote the progeny of parents whose germinal determiners are pure, or identical, for the respective trait or traits dealt with. Where an organism reproduces through self-fertilization or directly through the vegetative process of splitting, fragmentation or cutting, or through the agency of parthenogenesis — that is, the eggs developing without fertilization — the condition of a pure line is established. In cases of cross fertilization where the germinal determiners from opposite parents for a trait in question are identical, a situation similar to a pure line is encountered. Normally, organisms as they exist in nature are members of what is known as a population, that is, a mixture or combination of a number of pure lines. Selective breeding from a population really segregates the pure lines of which it is composed. Pure line, therefore, is applied to a group of individuals all of whom are descended from the same parental source and whose germinal constitution is quite definitely known.

If one were to take all the progeny of a pure line and study them from the standpoint of a single variation,

one would discover that most of them adhere closely to a single type. If the study were made statistically and a curve plotted, it would be found that the variations resolve themselves into a regular curve, similar to that shown in Figure 70. Most of the individuals would show the same degree of variation and would fall into

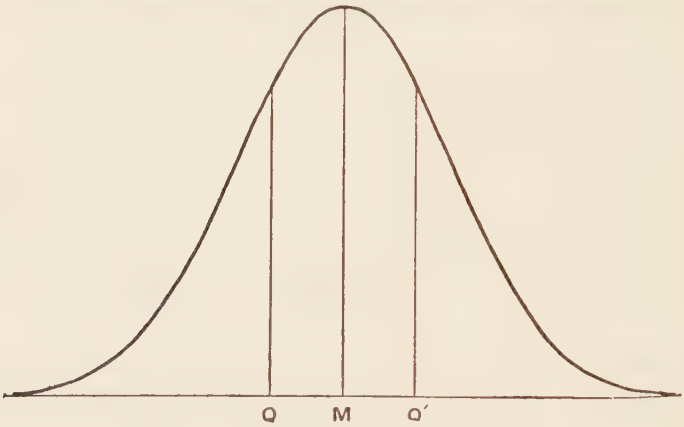


FIG. 70. CURVE OF NORMAL VARIATION

M denotes the mean, while Q and Q′ represent quartiles. The lines drawn from M, Q, and Q′ divide the area of the curve into four equal portions so far as numbers of individuals are concerned. (From Lock, *Variation, Heredity, and Evolution*. Courtesy of John Murray.)

the portion of the curve represented by the longest line from the base. In statistical language, this area is the mean of the curve of variation and represents the average of the group. Some, however, would not fall in this category, but would vary either in a plus or in a minus direction. Those individuals which showed the widest divergence, in either direction, would be found to comprise the fewest number. According to the Dar-

winians, continued selection of such individuals, namely, those showing the greatest degree of variation, ought ultimately to yield permanently modified or new types. This has not been found to be the case. The progeny resulting from repeated selections shows deviations practically identical with those of the pure line to which the parents belong. The mean, in every instance, remains about the same, and it is important to stress the fact that evolution can be brought about only by a permanent change or shift in the mean.

The most critical work on selection of fluctuating variations was done by a Danish botanist, Johannsen. This investigator took a population of the common garden bean which propagates by self-fertilization, and plotted a curve of variation of the size of the various beans; and he found that this gave him the normal frequency curve, that is, the curve of normal variation. The mean of this curve corresponded to the largest number in the population showing the most frequent size. He then selected from his population beans of various sizes, the largest and smallest, and others in between. Singling out nineteen such beans, he planted them carefully in separate plots, saved the segregated seeds, and by a rigid process of selection chose those individuals in their progeny which showed the most marked variation in size, in the hope that eventually he would obtain a permanent change in this direction. However, no such results were secured. While it is true that rigid selection brought about improvement, nevertheless the mean of variation, although slightly different in each case, adhered very closely to the mean of the curve for the entire population. The nineteen

beans with which he started became pure lines with respect to the character for which he was selecting, but an examination of their progeny revealed that the largest beans were no larger than those in the general population, and, similarly, that the smallest ones were just as small and no smaller than they were before rigid selection was undertaken (Figure 71). Johannsen therefore concluded that selection of the fluctuating variations simply sorted out all of the hereditary possibilities within the germinal constitution of the species, and did not add anything to it nor detract anything from it.

The general theory of natural selection is just as valid at the present time as it was in Darwin's own day. The truth is that no one has ever succeeded in overthrowing it, in spite of a disposition on the part of many individuals to discredit it on the ground that it has been completely abandoned by scientists. No greater fallacy has ever been promulgated. Dr. Samuel J. Holmes, of the University of California, sums up the situation in regard to natural selection as follows:

> While one may argue indefinitely as to whether natural selection can or cannot account for this or that structure, the status of the theory has become, I believe, more firmly established than it was in the time of Darwin. Whatever one may think of the adequacy of natural selection to account for the evolution of organic life, there can no longer be any doubt that organisms are preserved or eliminated on the basis of differences of hereditary constitution.[2]

[2] *Studies in Evolution and Eugenics,* New York, Harcourt, Brace, 1923, p. 24.

In reality, then, the modern evolutionist believes virtually everything that Darwin advocated, but he places the emphasis on discontinuous variations or

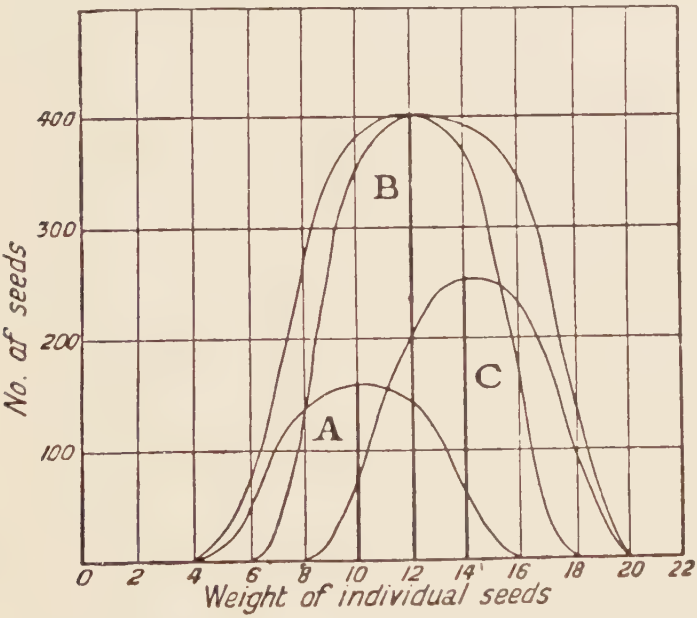


FIG. 71. CURVES OF VARIATION IN A POPULATION OF BEANS

A represents a curve for seeds varying between 4 and 16 centigrams in size, with a mean of about 10; B, for seeds between 6 and 18 centigrams, with a mean of about 12; C, for seeds between 8 and 20 centigrams, with a mean of about 14. The curve for the whole population is the outer one which encloses those for the pure lines. (From Goodrich, *Living Organisms*. Courtesy of Oxford University Press.)

mutations rather than on the continuous or fluctuating ones.

We now come to a more intimate consideration of

the third causal explanation of evolution, which, as already intimated, has been built up around the idea of discontinuous variations or mutations, and has been emphasized by evolutionists since the beginning of the twentieth century. In this connection it must be pointed out that to Darwin a mutation was a big, prominent variation, standing apart and showing up distinctly and conspicuously from the other individuals in the group. At the present time many students of evolution, while they recognize the importance of these saltations, nevertheless consider the majority of mutations as slight modifications, often so minute that the average individual undoubtedly would relegate them to the class of fluctuating variations. It must be pointed out, however, that these slight changes are not fluctuations; they appear as distinctive, minute alterations, some of them larger than others, and not necessarily emerging in logical sequence. As Dr. Morgan points out in his *Evolution and Genetics*,[3] if one were to consider a large number of mutant variations of a certain trait, they could be arranged in logical order, revealing a continuous degree of variation. On the other hand, the time of the appearance of these mutant changes is not continuous at all; rather, they come into existence sporadically, in a sort of hit or miss manner, oftentimes larger ones before smaller ones, and so on.

Hugo De Vries was one of the first to call attention to discontinuous variation as the sole agent responsible for evolution. In 1886, while roaming around in an

[3] Princeton University Press, 1925.

abandoned potato field some distance from his laboratory in Amsterdam, he discovered a number of discontinuous variations of the common evening primrose, *Oenothera lamarckiana*. This struck him as very peculiar, inasmuch as these different varieties were all growing in a similar environment and no selection of any kind could possibly have been going on. This led him to the conclusion that they were produced spontaneously. In order to study these phenomena more fully, he transferred the primroses to his experimental gardens and there they have continued to give off many new varieties which are practically of the nature of species. As a result of his observations and experiments on evening primroses, De Vries was successful in discovering about a dozen new types which had never before been seen or described. In *The Mutation Theory*,[4] De Vries elaborates fully the whole question of the origin of species through mutations.

We find mutations among flowers, fruits, and vegetables, many of them originating as "bud" mutations, which are perpetuated through cuttings. Much of the work of plant breeders undoubtedly has been of this character; they have isolated mutations through selection and kept them pure. Among animals, also, mutations have been shown to be quite common. One of the earliest known mutations is that mentioned by Darwin himself, namely, the short-legged Ancon sheep, which appeared spontaneously in Massachusetts in 1791. The Merino sheep, which replaced them because they had

[4] Chicago, Open Court, 1909.

a finer grade of wool, were also the products of mutation. Hornless cattle, tailless dogs and cats, various animals without hair, and albinos likewise are mutations. Some four hundred mutations have originated in the cultures of the fruit-fly *Drosophila*.

Geneticists believe that the way to advancement is through mutations, that is, discontinuous variations, and, as pointed out, these may be very large or very small modifications. Unlike the continuous variations, which cause the individual species to vary in a more or less somatic manner, the discontinuous variations are germinal in character, and bring about permanent changes. While there is considerable discussion as to how mutations originate, it appears certain that they are not the result of an accumulation of minute fluctuating variations. The outstanding facts about them are that they are real variations, that they breed true to type and do not revert to the mean from which they sprang. As for what causes a mutation, there are differences of opinion. Most biologists are convinced that it is produced by some stimulus which induces a permanent change in the gene or germinal determiner for the character which underwent modification.

Mutations are very interesting for numerous reasons. First, they breed true. Second, they are of more frequent occurrence than is generally supposed. Then, too, most of them soon pass out of existence, principally because they are not of use; and only those survive which are advantageous to the individual. Most mutations, however, are not of service. Finally, when we find mutations we also find an alteration in the germinal

constitution, often expressing itself by a change in number or by a realignment of the chromosome group. For instance, Professor Gates, of the University of London, and others have studied the mutations of De Vries and have found that, whereas the normal chromosome number of the species is fourteen, the number in some of the mutations is different, one possessing fifteen, another twenty, and so on. Dr. Metz, of the Carnegie Institution for Experimental Evolution, also has shown that some mutations of *Drosophila* possess changes in chromosomal number.

That mutations occur in nature has been known for a long time. It must be admitted, however, that very few of them make the species better adapted or fitted to its environment; most of them tend, rather, in the opposite direction, and these soon are eliminated in the struggle for existence. There are several others which, while they do not interfere with efficiency, nevertheless do no particular good, so that the organism is neither benefited nor harmed. The current opinion regarding the potency of fluctuating variations and mutations from the standpoint of evolution is that somatic differences in organisms are acquired by continuous or fluctuating variations, whereas germinal ones are produced exclusively through discontinuous variations or mutations. The former do not seem to induce any heritable creations, but apparently the latter lead definitely to those originations which make possible new species.

There are many things which remain unexplained in all of the above considerations of mutations. What was

the stimulus that brought about the definite change in the gene or chromosome number which accounted for that external, visible difference which made us call the new variation a mutation? No one can answer this question adequately, least of all a Weismannian. Does not there seem to be just as much mystery surrounding these sudden variations of De Vries as the fluctuating ones of Darwin? Furthermore, may not use and disuse, coupled with the parallel-induction of modifications in bodily structures and their germinal determiners, offer the way out of the dilemma? Finally, may not the minute, fluctuating variations, which appear to be transitory, leave their impress on the underlying protoplasmic nature of an individual so as to influence portions of the germ-plasm to become modified so slightly in one generation that it would be hardly perceptible; but if continued over a longer period, say, a few generations, the influence might accumulate and perhaps cause a distinctly new expression or change in such germinal elements and bring about a mutation?

Even though mutations be the absolute way in which distinct species originate, it does not at all obviate the general factors of natural selection as enunciated by Darwin, and De Vries does not object to their acceptance. Dr. Nutting, in an address before the American Society of Naturalists, said:

> It seems to me that we are justified in maintaining that Mendelism and the mutation theory, while forming the basis of the most brilliant and important advances in biological knowledge of the last half century, have neither weakened

nor supplanted the Darwinian conception of the "Origin of Species by means of Natural Selection." [5]

Two other causal explanations of evolution have been propounded by numerous investigators. These really are secondary to the above three, and in some instances they may accompany or supplement them. The first is that of orthogenesis, and when considered in serial sequence it must be regarded as the fourth causal explanation. Orthogenesis, that type of variation which develops along a specific line, was first propounded by Theodore Eimer, toward the latter part of the nineteenth century, to explain many of the variations which went on developing, whether or not they were of any use to the organism. Often these variations developed to such an extent that they not only become dangerous to the organisms individually, but actually caused them to become unfitted for the struggle for existence, thereby leading to their extinction. The Austrian botanist, Nägeli, propounded a similar view, believing that within every living thing there was some guiding force which caused it to unfold in definite directions, irrespective of the influences of the surrounding environment. Occasionally this guiding force brought about such a high degree of variation that the organism could not possibly retrace its steps, so that when environmental changes destroyed the efficiency of the alterations thus produced, the extinction of the species quickly followed. While orthogenesis may account for some degree of evolution, nevertheless

[5] "The Relation of Mendelism and the Mutation Theory to Natural Selection," *Science,* vol. 53, N.S. (1921), pp. 129–131.

very few scientists nowadays pin much faith on it as a major explanation.

The fifth and last causal explanation of evolution is the factor of isolation, particularly geographic isolation, through barriers of various kinds. Those who emphasize isolation state that while use and disuse, and natural selection, may operate to bring about variations either of a fluctuating or of a mutational kind, nevertheless through isolation the differences are kept distinct, so that the segregated organisms can inbreed and remain true to type. Some evolutionists believe that wherever there is no isolation, variations are quickly swamped, thus making it impossible to establish new varieties or species. Therefore, most forms of isolation really act in the same manner as selection does, picking out certain variations, keeping them distinctive, and intensifying them.

In concluding our discussion of the causal factors of evolution, we must repeat that until the present time no one of the above theories has been found adequate in all respects to explain the cause of evolution. Perhaps all of them are operative in bringing about new creations in the living world. Occasionally one factor might be more potent than another. It can readily be judged that possibly the most unsatisfactory part of evolution is that which concerns itself with the inherent factors that cause it. Thus far, there is no explanation that surmounts all of the difficulties. Perhaps truth lies in an explanation which is a sort of cross section of the five which have been considered in the present chapter. This, of course, should not be interpreted as an indict-

ment of evolution; it is merely a truthful statement of the facts. In spite of all this, the assertion must be reiterated, and with as much emphasis as possible, that all scientists, while they are still groping in the dark as regards the factors of evolution, are absolutely united in accepting the fact of evolution.

CHAPTER XIII

THE EVOLUTION OF MAN

In spite of his wonderful complexity and remarkable achievements, man is nevertheless an animal. He is bound and fettered to the rest of the animal kingdom by a thousand and one links, and is related particularly to those mammals which belong to the higher branches of the order known as the primates. It is significant that the various members of this order possess many traits in common. Practically all of them are arboreal in habit, practically all of them have developed some form of social life or organization. Then again, in regard to reproduction, they usually bring forth one young at a time, and invariably they give this offspring the very best care until it reaches a stage where it can shift for itself. So far as their senses are concerned, the primates are highly developed and exceptionally keen to detect enemies. This trait, coupled with their high degree of social coöperation, has developed in them the instinct of warning others in the group against dangers. Their behavior, in general, is so varied and complex that it puts them above most of the other members belonging to the class of mammals.

The animals embraced in the order of primates are usually classified into two sub-orders: the *Lemuroidea,* and the *Anthropoidea.*

The *Lemuroidea,* ordinarily called "lemurs," are often spoken of colloquially as the "half-apes" because they show so many striking resemblances to the ape family. They generally are found to inhabit the regions of India, the Philippine Islands, China, and the East Indies. Possessing certain characteristics which stamp them as the most primitive of the primates, they are considered by most students to be very close to the foundation stock from which the primates as a whole have evolved. In general appearance they do not differ markedly from many of the other typical mammals: they are quadrupeds, they do not attain great size, and their brain development is such that they are not placed very high in the scale of primate evolution. However, since they show a greater degree of social organization than the mammals below them, it is believed that they are related to the generalized forerunners from which not only they, but also the higher primates belonging to the second sub-order, the *Anthropoidea,* sprang.

The last-named unit is composed of two divisions, and these embrace the highest of the primates, including man. The first of these groups, the *Platyrrhini,* is composed of all of the new world monkeys, found mainly in regions of Central and South America. Inasmuch as these are comparatively primitive *Anthropoidea,* showing little resemblance to any of the forms that are more closely allied to the human being, they need not occupy our attention any further. The other group, the *Catarrhini,* embraces three distinct subbranches, technically known as families. The first of these consists of the tailed monkeys, good examples of

which are forms such as the baboons and sacred monkeys. The second branch includes the family of higher apes, known as *Simiidæ*. The common characteristic of these is that they do not possess a tail, or, when such a structure is present, it is extremely short and stub-like. The *Simiidæ* embrace such well-known representatives as the gibbons or the small apes, the orang-utans, which reach a height of between three and four feet, the chimpanzees, about five feet tall, and the gorillas, which grow to a height averaging close to five and a half feet. The third and final branch of the *Catarrhini* consists of the human family, technically known as the *Hominidæ*, and this embraces the genus *Homo,* to which modern man, consisting of the single species *Homo sapiens*, belongs. Here, also, must be included the immediate ancestors of man, whose fossils have been unearthed in various regions of the world during the last seventy-five years. So far as man's immediate relationship is concerned, he appears to be linked much more closely to such apes as the chimpanzee and the gorilla than to any of the others which are known.

As stated at the beginning of this chapter, when man is studied from a biological standpoint he must be regarded, not only as the highest type of animal, but also as one related by innumerable ties to the lower forms, particularly those belonging to the higher group of primates. From the structural standpoint, he shows certain striking resemblances, both external and internal, especially to the higher apes. When, for instance, we compare the skeleton of man with that of a chimpanzee or gorilla, we find a very close relationship of

the parts, so close that we are led to the conclusion that the structures are all homologous. The various other organ systems — the circulatory, digestive, excretory, etc. — show similar features in common, with minor differences. It is true that certain parts may become more specialized or developed in the one than in the other, but aside from these lesser distinctions they reveal the same identities of organization. As an example of structural modification going hand in hand with environmental adaptation, the differences exhibited by the limbs of the higher apes and man may be mentioned. In the orang-utan, chimpanzee, and gorilla the forelimbs are very much longer, proportionately, than in man, and the legs are considerably shorter. This feature, undoubtedly, is an adaptation to the typical habitats of the organisms in question, the higher apes being tree-dwelling forms, whereas man has become almost exclusively a ground-dweller. There are some primitive races of men who still live among trees and build their huts in them, but they do this chiefly for protection. It is commonly believed that the group from which man directly ascended must have lived, for a short period at least, in trees, as do the present-day apes, but that in the course of time, as man developed more cunning and better means of protection, he left the tree tops and sought the open plains.

From the standpoint of embryology, also, man shows his animal ancestry. The higher apes and man undergo a similar internal development. The time of gestation is almost the same for both embryos, their stages and structures being so similar that it is extremely difficult

for the average person to distinguish them. Moreover, after birth, the mother in both instances takes a great deal of care of her young, nursing and protecting them for a considerable period of time until they reach an age when they are able to live independently. In the case of the apes, the young, before they reach sexual maturity, are much like human beings, quite lovable and tractable; but as sexual maturity comes on they become rather sullen and vicious. Those who have studied the higher apes, either in confinement or in their natural haunts, report that they become most dangerous to handle when they reach this stage in their development. Many biologists hold that in the evolution of the higher apes and man the essential difference first asserted itself in the development in man of a small amount of intelligence which enabled him to exercise some control over his purely instinctive desires and impulses; in other words, man evolved that form of nervous coördination which enabled him to regulate and curb many of his primitive instincts. On the other hand, in the lower forms no such evolution occurred, and here the purely instinctive behavior has had full sway, dominating the animals to such an extent that they have developed into ferocious and vicious types. From an evolutionary point of view, therefore, man may be said to have ascended, while the apes have remained stationary.

It is thus evident that, from the standpoint of structural and developmental characteristics, man's relationship to the rest of the animal kingdom is such that the zoölogist must classify him as a mammal belonging

to the order of primates, and related especially to the forms included in the group of old-world apes, such as the chimpanzee and gorilla. Sir Arthur Keith, in his recent presidential address before the British Association for the Advancement of Science,[1] asserts that the close relationship between these two ape forms and the human individual can lead to but one conclusion, namely, that of identity of origin. He says further:

> Our geological search, . . . has not produced so far the final and conclusive evidence of man's anthropoid origin; we have not found as yet the human imago emerging from its anthropoid encasement. Why, then, do modern anthropologists share the conviction that there has been an anthropoid stage in our ancestry? They are no more blind than you are to the degree of difference which separates man and ape in structure, in appearance and in behavior. I must touch on the sources of this conviction only in a passing manner. Early in the present century Professor G. H. F. Nuttall, of Cambridge University, discovered a trustworthy and exact method of determining the affinity of one species of animal to another by comparing the reactions of their blood. He found that the blood of man and that of the great anthropoid apes gave almost the same reaction. Bacteriologists find that the living anthropoid body possesses almost the same susceptibilities to infections, and manifests the same reactions as does the body of man. So alike are the brains of man and anthropoid in their structural organization that surgeons and physiologists transfer experimental observations from the one to the other. When the human embryo establishes itself in the womb it throws out structures of a

[1] "Darwin's Theory of Man's Descent as it Stands To-day," *Science*, vol. 66 (1927), pp. 201–208.

most complex nature to effect a connection with the maternal body. We now know that exactly the same elaborate processes occur in the anthropoid womb and in no other. We find the same vestigial structures — the same "evolutionary postmarks" — in the bodies of man and anthropoid. The anthropoid mother fondles, nurses and suckles her young in the human manner. This is but a tithe of the striking and intimate points in which man resembles the anthropoid ape. In what other way can such a myriad of coincidences be explained except by presuming a common ancestry for both? [2]

In spite of the fact that man is closely related to the forms which have been mentioned, yet he can be clearly distinguished from them. We must come, therefore, to the question as to what really differentiates him. If there is one feature that especially marks him off from the rest of the animal kingdom, it may be said to be his psychical development. While in many respects man shows the same psychological behavior as the higher primates, yet in the one feature which has already been mentioned, namely, his intelligence, he may be said to be much higher than they, being really in a class by himself, dominating the entire animal kingdom.

The higher apes and humans, although they show the greatest development of brain power, nevertheless differ markedly from each other in this respect. Man has almost twice the brain mass possessed by the apes, and to some extent nearly twice the brain power. Among

[2] *Ibid.*

the higher apes, the chimpanzees are known to have the greatest degree of mental attainment; but their average brain mass is found to be only seven hundred cubic centimeters, as compared with close to fifteen hundred cubic centimeters for that of man. This difference in brain mass, which after all controls the behavior of the organism, undoubtedly is the basic feature which differentiates human beings from apes. The chimpanzee, and particularly the gorilla, may reach an enormous bodily size, the latter form often weighing well over four hundred pounds and having a chest measurement close to seventy inches; yet the largest ape may have a brain mass considerably less than one-half that of even the smallest human adult. The inevitable conclusion is that man, from the standpoint of nervous coördination, behavior, and the development of the higher faculties, stands pre-eminent, at the pinnacle of the entire animal kingdom. He is the highest product in this creation that we call evolution.

Having briefly traced the relationship of man to the rest of the animal kingdom, we are now ready to concern ourselves with him for the express purpose of finding out more definitely his mode of origin and evolution. Can any of the recent fossil finds solve this mystery? Indeed they can, and therefore it will be well to study these relics of ancient times a little more closely. The discoveries of the last century are important in revealing the later chapters in the history of man, but as yet the earliest records which bind the human family to the lower forms of mammals have not

been discovered. Just when man branched off separately from the rest of the animal kingdom, therefore, remains an unsolved problem. It is now known that the oldest finds belong to an age of more than a million years ago, and, taking other facts into consideration, it is believed that the original branch which led to modern man must have emerged about sixteen or seventeen million years ago, when the group to which the present-day monkeys belong also originated. Scientists believe that man probably took his independent origin at the same time when such domestic animals as the horse, the camel, and the elephant flourished. The history and age of these useful animals have been quite definitely established, and this information is, of course, extremely helpful in enabling us to reach a conclusion regarding the antiquity of man.

It has always been very interesting to consider the exact source from which man originated. Two theories have been propounded to answer the query. When first evolution was considered seriously by science, shortly after the promulgation of the Darwinian conception, there arose what is known as the ape-man theory, according to which man sprang directly from some ape-like ancestor. To some extent this hypothesis was espoused by Darwin, Huxley, and Haeckel. These old naturalists did not, of course, have at hand nearly as much material as we now possess, but they saw many similarities between apes and men and came to the inevitable conclusion that man originated from some ape-like ancestor. Many scientists and laymen revolted against such a contention and they developed the

second view, that man did not spring from any of the apes but that the present apes and men originated side by side, in a sort of parallel fashion, from some common prehistoric ancestral group, which combined in certain respects the characteristics of both of these independent branches of primates. In other words, this second conception contends that the human and the ape families are derived from a common source. One branch went off in one direction, emphasizing and specializing along human lines, while the other evolved in the direction of the apes.

This question of how man originated, and from what he originated, has attracted the attention of a large number of investigators in recent years; and at the present moment there is considerable controversy as to which of these two explanations is the more tenable. One group believes, with Dr. Osborn, the distinguished evolutionist and paleontologist, that man originated as a separate entity from a common stock which also gave origin to the branch from which the modern apes sprang as a separate entity. This group holds that man never had a distinctly ape-like ancestor, but that the human family, in common with the apes, emerged from an ancestor that showed many combined characteristics of ape and human. As to how far back this common ancestral stock lived, no one can state definitely, but estimates range from seventeen million to forty million years ago. The branching-off process occurred a little later on, taking definite shape nearly thirty-five million years ago, and during this period there probably existed distinct pre-human types. Judging from our knowledge

of geologic history, these pre-human forms lived at the time when the horses, camels, and elephants first became established.

Thus far, no human remains of this early period have been unearthed. The discoveries which have been made are those of the most recent ancestors of man, but it must be remembered that there is a wide gap between them and the remote ancestral types. Undoubtedly, as regions are more adequately explored, more discoveries will be made, and much of this gap will be filled in. The races of men which existed between the common ancestor and the true men have been spoken of as "pre-human," and those which followed them and lived until modern man arrived on the scene have been named "dawn-men." The advocates of Osborn's view assert that the pre-human originated from the group of organisms which were ancestral to apes and humans, and that these, in turn, produced the dawn-men from which the modern races of men have developed. The fossil finds, with only one or two exceptions, which may perhaps be those of dawn-men, belong mainly to recent times. Thus far, no pre-human remains have been discovered.

The second group believes in the hypothesis which is sponsored by Dr. William K. Gregory, a colleague of Dr. Osborn at the American Museum of Natural History. Dr. Gregory is a noted comparative anatomist and paleontologist, mainly the former. He holds that the higher apes, such as the chimpanzee and gorilla, and the human species sprang from some common generalized ape-like ancestor who was much more

primitive and less highly specialized than any of the apes in existence at the present time. These early forms must have lived at first in trees, and undoubtedly one branch of them became isolated in a region where there were few forests and vast stretches of open country, with the result that the individuals could no longer exist in trees and therefore had to accustom themselves to a life of roaming about on the ground. Inasmuch as they were highly generalized they could readily adapt themselves, and gradually there evolved a succession of races of ape-men which terminated in a distinctly human kind. Dr. Gregory thinks that the isolation of the original branch of generalized apes which produced the ape-men occurred about sixteen million years ago, but that the distinctly human types originated approximately four million years ago. As for the fossil finds which have thus far been made, Dr. Gregory believes them to be actual transitions between the more generalized ape-like ancestor and modern man. In arriving at this conclusion, Dr. Gregory bases his contention principally on comparative anatomy, and the resemblances between the human and ape-like primates. For example, he mentions the human foot and shows that it possesses definite ape-like characteristics. At about nine weeks in human prenatal development, the large toe stands distinctly apart from the rest of the toes, curving in toward the others, very similar to the manner in which it is specialized in the apes for grasping the limbs of trees. There are numerous other features of similar character which Dr. Gregory thinks cannot be interpreted in any way except on the basis that they

are reminders of an ancestral forerunner that possessed these characteristics.

In an article entitled "Did Man Originate in Central Asia?" Dr. Gregory states his view as follows:

So many and deep-seated are the anatomical and physiological bonds between the anthropoid apes and man that Professor H. H. Wilder has proposed to recognize this relationship by referring the existing anthropoid apes and man to a single zoölogical family, the *Hominidæ*. In other words, according to the viewpoint held by Wilder, Schwalbe, Keith, Elliot Smith, Sonntag, Tilney and many other recent investigators, including the present writer, the existing anthropoids and man are merely divergent branches of a primitive anthropoid stock, exactly as held by Darwin. To deny at this date or to seek to minimize the importance of man's close relationship with the chimpanzee-gorilla stock is to shut one's eyes to a vast accumulation of well-tested facts. To attribute to parallelism the thousands of resemblances between man and chimpanzee is equivalent to saying that no zoölogical classification founded on deep-seated anatomical resemblance has any objective validity.

No matter how many millions of years ago man and the chimpanzee parted company, the anthropoid apes are still justly regarded as man's nearest relatives among existing mammals, and the most intensive research has brought forth no adequate reason for doubting that man is an offshoot from the Old World Primates and in particular that he represents a highly modified offshoot of the anthropoid stem.

It is true that a few authors have failed to grasp this fundamental fact and that all sorts of queer theories have been promulgated, but at the present time the weight of a great many independent investigations is overwhelmingly

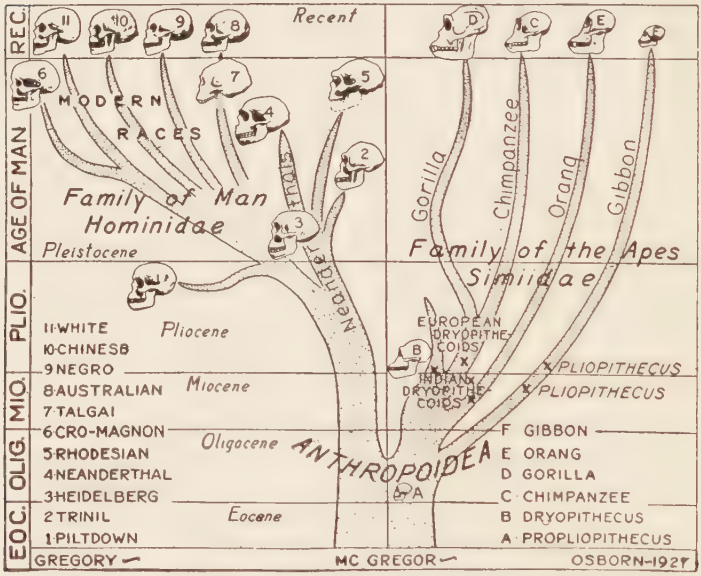
in favor of the view that at one time man passed through an arboreal stage of life, not remaining there long enough to become over-specialized in that direction like the existing anthropoids, and that at a later period he came down out of the trees, preserving his erect arboreal posture and becoming a bipedal cursorial animal.[3]

Thus we find a slight difference in these two conceptions. One group, headed by Dr. Osborn, says that man never went through an ape-like transformation; the other, headed by Dr. Gregory, says that the apes sprang from some previous type and founded a generalized branch, and that this, in turn, gave origin to man and the higher apes. Both of these points of view are based on good evidence and are perfectly sincere. Whichever of these is the true interpretation, it is evident that man's history is very recent as compared with the long chain of animal evolution, and that he took his origin from forms which were less specialized than those in existence at the present time. Figure 72 shows the manner in which man and the apes are related. So much is certain — that man and the apes show a close kinship; their structures are strikingly similar in so many respects that often it is very difficult to distinguish between them. It does not matter whether we adhere to one set of theories or to the other. We need not be terribly shocked to think that perhaps we are descended from the apes. Is there not great hope in the thought that man has risen from such lowly forms to his present status, and may we not anticipate that, since in all likelihood this was the case, man has the

[3] *Scientific Monthly*, May, 1927, pp. 385–401.

power to evolve to still higher levels? There is tremendous promise in such a view!

Evolution teaches that the whole animal world is united and that we are merely the highest products of that creation we call evolution. Within the next fifty



Courtesy of Science

FIG. 72. THE EVOLUTION OF MAN AND OF APES

years, probably, many of the mysteries surrounding man's origin will be solved, because more and more ancient fossils and traces of old cultures will be found. By the aid of these discoveries we will then be able to decipher the human record a little more clearly.

Another interesting question regarding man concerns the place of his origin. In recent years scientists have

accumulated numerous facts which have led them to the conviction that man originated somewhere in Asia, probably in that region now known as Mongolia, Tibet, and Chinese Turkestan, which for many centuries remained unexplored. This area covers a wide range of territory, including mountains and valleys which have been sparsely settled with races of people who have lived there from time immemorial. The reasons for believing that Asia is the birthplace of man are numerous. A study of this continent soon reveals that it has tremendous size, as well as great diversity of climate. Where such a combination of factors exists, animals and plants develop rapidly and soon give origin to large numbers of different types. Since Asia contains the oldest civilization of which we have any record, it seems logical to assume that the human family had its greatest length of existence there. Another reason for adhering to such an opinion is the fact that Asia is now, and has been in past generations, so closely linked up with other continents that migrations from it could take place readily. Thus having originated and become established in Asia, man could migrate easily to the other areas contiguous to the Asiatic continent and, in turn, populate them. What is known of the past history of animals and plants in general indicates definitely that Asia is the original home of the most highly developed organisms, including many of the common domesticated types. Furthermore, from what is known of the *rôle* played by man in domesticating animals at the present time, it seems logical to conclude, as most scientists do, that in past generations man has also been

the guiding force for domesticating the animals which lived during those times.

Perhaps the strongest evidence for believing that Asia, particularly the region embraced in Central and Northern China, is the place where man originated comes from various discoveries of human cultures which have been made in these localities in recent years. In 1921, Dr. Andersson, of the Geological Survey of China, found a rich deposit of fossils in an ancient cave at a place called Chou Kou Tien, southwest of the city of Pekin. These deposits were later studied and described by Dr. Zdansky of Upsala. The finds consisted of fossil bones of numerous mammals, including such forms as bats and monkeys, and also two teeth, one a premolar and the other a molar, which have characteristics similar to those of modern human teeth. The deposit in which these teeth were embedded has been estimated to belong to the time of the late Pliocene or early Pleistocene period, approximately two or three million years ago.

In 1923 two other investigators, Père Licent, director of the Tientsin Museum, and Père Teilhard de Chardin,[4] of the Paris Museum of Natural History, uncovered additional evidences of human cultures in the province of Ordos in Northern China. These consisted of crude quartz and flint implements similar in many respects to those previously discovered in certain parts of Europe and known as the Mousterian and Aurignacian implements. Mixed with them, bones of such

[4] "Fossil Men in China and Mongolia," *Natural History*, vol. 26 (1926), pp. 238–245.

complex vertebrates as the sheep, gazelle, wooly rhinoceros, hyena, and ostrich also were found. Finally, the various expeditions of the American Museum of Natural History, headed by Dr. Roy Chapman Andrews, have brought back positive results of man's early existence in Asia, especially in those regions of China which have been mentioned. Concerning these finds, Dr. Gregory remarks:

> From later ages, including Mesolithic, Neolithic and pre-Mongol horizons, Dr. Nels C. Nelson of Dr. Andrews' expedition has collected a large series of flint implements and other cultural remains in different localities in Mongolia and China. In this way the very remote past of man in these countries is gradually being tied in with later history, the geologists and archeologists together tracing the rhythmic alternation of more arid and more humid climates and their effects upon the human populations.[5]

On the basis of all of the facts, especially those revealed through a study of the previous history of the earth, it is believed that in Asia those conditions existed which made possible the development of the stock from which was evolved the direct ancestor of the modern human family. It has been ascertained that in Central Asia there were tremendous forests interspersed with large lakes and streams stretching over a great part of that country. The primates, especially those which lived in the trees, undoubtedly were very abundant in these regions, and the fossil records which have been found confirm this conclusion. It is also known that many of these forest areas disappeared, because glaciers came

[5] *Op. cit.*

down from the north to wipe them out, leaving in their place vast patches of open, arid regions. As the wooded territory shrank, some of the stock of primates which were the immediate progenitors of man were cut off from an arboreal habitat, and therefore they had to adapt themselves to the changed conditions of the environment. Those that could so adjust themselves soon developed a more erect posture and a more highly specialized nervous system, with the ultimate result that in due course of time they gave origin to the human species. Through migrations the various races of man, ancient as well as modern, have developed.

The oldest fossil human remains have been discovered in Asia at a place called Trinil on the island of Java, in the sands of the Sula River, also called the Bengawan River. Here in 1891 Dr. Eugene Dubois, a Dutch physician, found a skull cap, three molar teeth, and a left thigh bone. These bones were scattered over an area of about fifty feet, and from a careful study of them several very important generalizations have been made. The region in which the bones were found shows that the individual to whom they belonged must have existed at least a million and possibly two million years ago. This find has been called the Java Ape-man, scientifically known as *Pithecanthropus erectus* (Figure 73,1). The teeth show that their owner employed the same rotary motion in chewing as human beings now do; they are fairly modern except that they are slightly larger than present-day teeth. Furthermore, they show that the Java Ape-man had, in some limited degree, articulate speech, that is, that he could make sounds

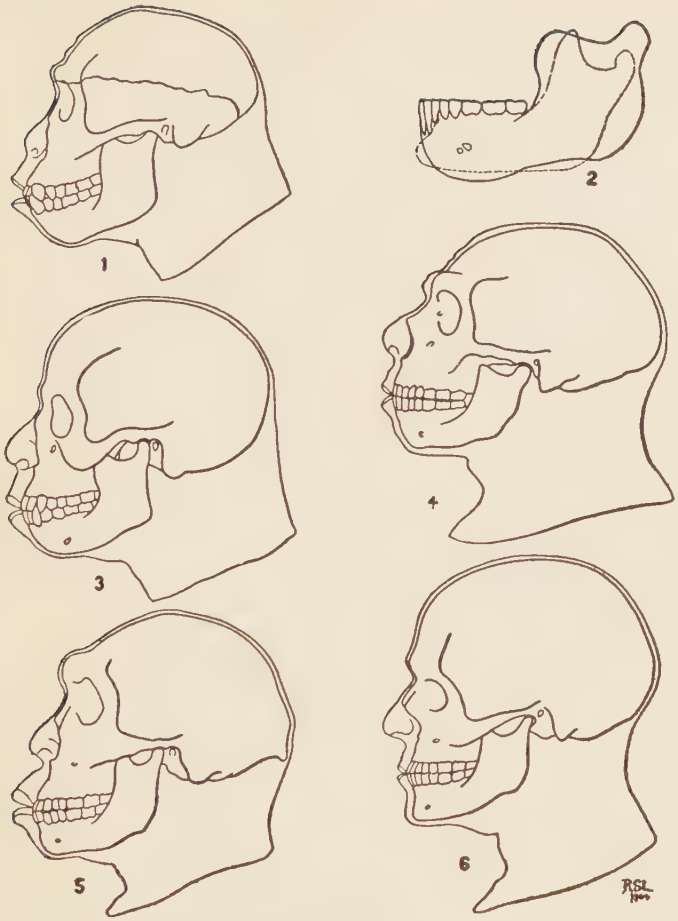


FIG. 73. PREHISTORIC HUMAN SPECIES

1, Java ape-man, *pithecanthropus erectus*. 2, Jaw of Heidelberg man, *homo heidelbergensis*, compared with jaw of modern man (in dotted lines). 3, Piltdown man, *eoanthropus dawsoni*. 4, Neanderthal man, *homo neanderthalensis*. 5, Rhodesian man, *homo rhodesiensis*. 6, Crô-Magnon man, *homo sapiens*. (From R. S. Lull, *Ways of Life*. Courtesy of Professor Lull and Harper & Brothers.)

and perhaps converse in his own characteristic way. Comparative anatomists can deduce all of these facts from an intimate study of certain parts. The thigh bone shows nothing peculiar or startling, except that it must have been affected by a bone disease similar to rickets. In this respect, and in other respects of structure, it is just like the thigh bone of modern man. However, the skull cap is peculiar, revealing that the individual to whom it belonged was of a low-browed type, possessing a brain very much smaller than that of modern man, probably only two-thirds as large. Dr. McGregor, of the American Museum of Natural History, has reconstructed this ape-man, revealing a face much like that of a modern gorilla.

The next human find was made in Europe. The fact is, indeed, that most of the human fossils have been found in Europe, a few in Africa and the United States, and only one in Asia. This second find is known as the Heidelberg man, *Homo heidelbergensis* (Figure 73,2), because he was found about ten kilometers from the city of Heidelberg in southern Germany. The remains were discovered in a river bed and consisted of the lower jaw, complete in every detail. This jaw looks very much like that of the modern gorilla in all respects; it is very massive, lacks a chin, slopes backward, and appears so prominent as to indicate clearly that the head of its owner was massively constructed. However, the structure of the teeth is entirely human. From this find Dr. McGregor has reconstructed the missing portions of the skull, indicating that the face must have appeared bestial and ferocious, somewhat similar to that

of the gorilla type represented by the ape-man of Java. This race of men also must have lived about a million years ago, very close to the time of the ape-man of Java, and it is regarded by scientists as the oldest race of European human beings thus far discovered.

In Sussex, England, in 1911, the so-called Piltdown man, *Eoanthropus dawsoni* (Figure 73,3) was found. This find consisted of fragments of the skulls of two individuals, one containing certain portions of the skull that the other lacked. The cranium is extremely heavy, averaging about four-tenths of an inch in thickness. There has been considerable controversy as to whether these remains are those of true apes or of humans, but most students are inclined to the latter view. Basing their opinions on reconstructions, evolutionists and paleontologists believe that the face of the individual to whom the bones belonged appeared ferocious. It is estimated that these human beings existed some four or five hundred thousand years ago, probably in the region of Piltdown, county of Sussex, England.

The fourth find is the so-called Neanderthal man, technically known as *Homo neanderthalensis* (Figure 73,4). This is perhaps the best known of all of the ancient races of men, because the finds of skeletons of its members have been more numerous than those of others and because the skeletons themselves have been more complete. In 1848 the first of the Neanderthal finds, consisting of a complete skull, was unearthed in the region of Gibraltar. Then followed other discoveries of similar skeletons. In 1856, in Germany, in

the Neanderthal Gorge of the Diesel River, a tributary of the Rhine, a complete skeleton of this type of man was found. About thirty years later (1887) two other skeletons were uncovered in Belgium. All of these show exactly the same characteristics and belong unmistakably to members of the same race. Many students of evolution think that the Neanderthals evolved as an offshoot from the Heidelberg race of men. Judging from the skeletons, the Neanderthal males reached a height of about five feet three inches, whereas the females were a little shorter. The vertebral bones of the neck indicate that this region of the body was rather short, stocky, and very muscular, similar in appearance to the neck of modern apes. On the other hand, an examination of the skull indicates that the brain was exceedingly large, approximately as large as that of modern man. Moreover, it has been definitely established that the Neanderthal race was made up of craftsmen, who had developed a great deal of skill in the fashioning of flint into various implements which they could utilize in their struggle for existence. Ethnologists state that offshoots from this group undoubtedly exist at the present time in certain regions of Holland and Ireland, and may also be noticed among some of the natives of Australia. Most biologists, however, think that the Neanderthal race, as such, is now entirely extinct, and that the present-day forms which have been mentioned are merely remote offshoots. There is considerable debate as to when the Neanderthal stock lived, estimates varying from seventy-five thousand to three hundred thousand years ago; but one hundred

and fifty thousand years ago is a fairly conservative calculation.

In 1921, in northern Rhodesia, Africa, the remains of a skull belonging to the so-called Rhodesian man, *Homo rhodesiensis* (Figure 73,5), were discovered. This skull shows that in most respects the individual was comparatively close to modern man; however, there are certain salient differences. The characteristics indicating that the individual was quite close to us are that the teeth show caries, or decay, and the wisdom teeth, or third molars, are of nearly the same size and proportion as in modern man. This last characteristic is very convincing, for in modern man the wisdom teeth have fallen into disuse and are undergoing atrophy; in some instances they do not even come through the gums, remaining degenerate structures which are gradually disappearing. In the other races of men which have been mentioned, such was not found to be the case; the wisdom teeth remained large, showing that they were functional structures as in the other mammals. In other respects the Rhodesian individual was rather primitive. The skull and portions of the lower jaw show distinct ape-like characteristics, the eye-sockets in particular being more or less square, as in the gorilla, rather than round, as in the human species of today. It is rather difficult to state accurately when this race of men existed, but estimates range from fifty thousand to a hundred thousand years ago.

The last race of men to be mentioned is the modern one, *Homo sapiens* (Figure 73,6), which undoubtedly originated about fifty thousand years ago. It is believed

that two varieties of the species *Homo sapiens* preceded the present existing race. These were the so-called Crô-Magnons, and the Grimaldi races, both showing that they are entirely modern in every respect, with only minor differences. The representatives of the Crô-Magnon race show that they were, as far as physique is concerned, the finest specimens of the human family that ever lived, including the present types. The specimens upon which this deduction is based were found mainly between 1853 and 1856. In 1852 specimens were unearthed in Gower, Wales, but they were lost. Then in 1856, at Crô-Magnon, in France, five skeletons were discovered. There was an old man, a mature woman, a child, and two young men. All of these skeletons show that this was a race of giants, the men reaching a height of about six feet two inches, and the women being somewhat smaller, about five feet five inches tall, which is a little more than the average height of human females of the present day. They doubtless constituted a fine looking race, with a brain capacity just about as large as ours. Living side by side with the Crô-Magnons was the Grimaldi race, specimens of which have been found at Mentone, France. At this place, also, was found a perfect skeleton of a Crô-Magnon man. The Grimaldi finds consisted of two skeletons, the one that of a woman, the other that of a boy. These show negroid traits, similar to those found in modern negroes. The Crô-Magnons, however, show Caucasian characteristics. It is believed that the Grimaldi race of men reached Europe from Africa by crossing the Mediterranean Sea, but that for some un-

known reason they never successfully established themselves there. They were perhaps outstripped and forced to return to Africa by the Crô-Magnons. Both races were skilled workers in iron, flint, and stone. Dr. Osborn has written a very interesting book entitled *Men of the Old Stone Age*,[6] which helps us to picture the times and some of the conditions under which they lived.

This, in brief, completes the absorbing story of the emergence of man. It is a tale which reveals the same fascinating details of evolution as everything else in nature. However, the revealed evolutionary history of man is less complete by far than that of many of the other organisms beneath him, and undoubtedly there are good reasons to account for this. The one thing which largely distinguishes man from the lower primates is his nervous system. Mentally man has progressed to far greater heights than have any of the other primates, and therefore he has been better able than they to grapple with and overcome the unfavorable conditions of environment. Furthermore, his mental evolution has also brought with it some form of social organization, with the result that he has developed ideas of his relationship and responsibility to other members of society. Early in his development he began to ponder on questions of life and death, so that he soon formed conceptions regarding life after death. He took many precautions to care for those individuals who died, burying, burning, or in some other way caring for them. During his lifetime he also was

[6] New York, Scribner, 1919 (3d ed.).

intelligent enough to refrain from going into dangerous localities where he would be trapped under conditions that would preserve him for future generations. Therefore, fossils of man are extremely rare, as compared with those of the lower animals which, with their limited intelligence, could not evade disaster so readily.

One other reason for the scarcity of fossil human remains is found in the fact that man has not been interested in himself as much as in other forms. Only in comparatively recent years, indeed, has such interest been aroused, and the finds which have been made are really the products of recent efforts. In view of the present interest in man, it is quite safe to predict that the most important finds of human ancestry probably will be made within the next fifty years. Still another reason for the existence of such few and scattered evidences of human evolution lies in the fact that the regions which are now considered the place of the origin of man until very recently have been inaccessible to explorers. These localities have been inhabited by backward peoples, among whom explorers and scientists have not been welcome. However, as civilization develops and as modern education expands, these oldest places on the earth will undoubtedly be opened up for scientific exploration. Then may we find the various "missing links" in the history of man's evolution!

CHAPTER XIV

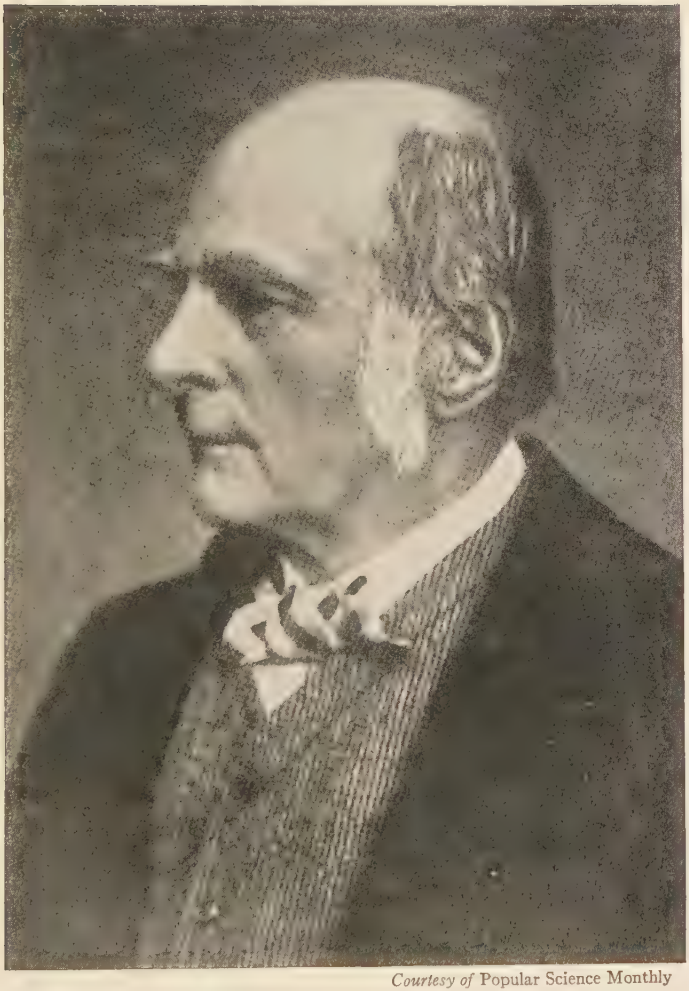
THE FUTURE EVOLUTION OF MAN

Evolution, as applied to man, really implies the production of a better race of human beings. It means that the human family must take stock of itself and seriously consider the forces and factors which have made possible its development to the present level of attainment, and then, by means of the knowledge thus gained, apply those principles which will produce a race of individuals better fitted, physically and mentally, to cope with the problems of modern civilization. In this connection, the fact must not be overlooked that it is only within recent years that man's future welfare has been seriously considered. Man has been so busily engaged in studying the things about him that he has lost sight of the fact that he also is an animal, subject to the same evolutionary laws and principles which have operated to mould the forms beneath him. Until comparatively recent times, man has looked upon himself as an organism belonging to a distinct class, with little relationship to the rest of the organic world; and, therefore, while he was willing to devise measures for evolving more perfect types of plants and animals, at the same time he completely ignored himself.

During the last century, when the topic of evolution began to engross the minds of scientists, it was shown

that man, while he represented the highest animal in the evolutionary tree, was nevertheless subject to the same fundamental factors which dominated the other representatives of the living world. Therefore, if man wished to progress in those directions which he considered best, he would consciously have to apply to himself those biological principles which had been found to hold good for the improvement of the rest of the animal kingdom.

In recent years, many students have been giving this subject earnest consideration, with the result that there has arisen a new science having for its sole aim the application of those evolutionary laws which will lead to the emergence of a better race of men and women. This science, known by the name of eugenics, came into existence principally through the efforts of Sir Francis Galton (Figure 74), the great English scientist who not only called attention to many of the tendencies in modern society which were undermining the vigor of the race, but also emphasized some of the remedies which were necessary to produce a higher type of human being, insuring a finer and nobler civilization. In 1883, Sir Francis Galton defined eugenics as "the study of all of the agencies under social control which may improve or impair the inborn qualities of future generations of man, either physically or mentally." Literally, it may be said to mean the science concerned with the evolution of man, and its real purpose is to bring improvement within the human family through the biological agency of reproduction. In reality, then, eugenics occupies itself seriously with the past and



Courtesy of Popular Science Monthly

FIG. 74. SIR FRANCIS GALTON

present status of the human individual for the purpose of insuring the development of a better type.

There is great need for eugenics from numerous standpoints. From an educational standpoint, eugenics teaches us that we must pay more attention than we have hitherto paid to the individual differences exhibited by children. Until the present time, educators have classified pupils into grades largely according to age rather than according to their innate capacities. Students of human biology and psychology have shown definitely that among children of the same age a number of groups differing in both physical and mental capabilities may be found. The eugenist believes that the modern school should adapt itself to the specific needs of these respective units, rather than treat them as a single entity. Undoubtedly, such a system of education would be much more expensive than the present system, but the fact must be recognized also that it would be infinitely more efficient, and ultimately lead to a permanent economy; for, after all, the greatest investment that a nation can make is one which insures the finest development of its youth, and hence the highest type of citizenship for the future.

In this connection, it must be mentioned that very few people are aware of the fact that in the United States the per capita amount of money expended for the education of our normal children is less than that expended for the care of the defective persons housed in public institutions. In the State of Oregon, for instance, the annual per capita cost for children in the grade schools is approximately $50.00; for a student

in high school it is about $90.00, and for an individual attending normal school, college, or university it is close to $300.00. In the case of defectives, on the other hand, the cost mounts to nearly $400.00; but this figure does not take into consideration county, municipal, or private contributions. A similar or worse condition of affairs exists in nearly all of the other states. To say that we are spending annually in the United States considerably more than $500,000,000 on the care of the insane, feeble-minded, paupers, and other dependents, is to speak conservatively.

There also is need for eugenics from a public standpoint. Relatively few individuals have an adequate understanding of such fundamental topics as the effects of environment on children, the manner in which traits are transmitted from one generation to the next, and the influences of racial poisons and diseases on the unborn child. An acquaintance with eugenics would help the public to understand some of these problems and particularly would make them realize how they affect the human family. People in general have formulated the queerest notions concerning the so-called "prenatal influences," particularly in regard to maternal impressions. If a child happens to be born with peculiar marks on its body, immediately the "wise ones" conclude that the pregnant mother was frightened by some object, or craved a certain delicacy which could not be supplied at the time, and that, in either event, a mysterious something impressed the child with a mark bearing a close resemblance to the influence concerned.

Conceptions such as these have been firmly ingrained in the minds of people for countless generations, and often may be encountered in literature. Oliver Wendell Holmes spun his story of *Elsie Venner* around such a theme. Anatole France, in his novel *Little Pierre,* also relates an amusing incident of this sort which occurred when the little fellow was born. No doubt the reader will recall similar instances; needless to state, all of them are erroneous ideas which a knowledge of eugenics helps to dispel.

Concerning the effects of poisonous substances and diseases on the unborn child, more definite information is available. Poisons taken into the body of the pregnant mother, in appreciable quantities and at regular intervals, may cause an abnormal state in the membranes surrounding the developing child such as to produce profound modifications within it, often leading to physical defects, mental disorders, degeneration, premature birth, and even death. Disease also may so weaken the pregnant mother as to bring about unhealthy internal conditions which may tend to impair the growing embryo either physically or mentally. As far as is known, diseases of themselves are not inherited, but they may affect the offspring by producing within the mother unwholesome prenatal conditions which prevent normal development.

Certain diseases of the reproductive organs are of vital importance in relation to the future of the human family. The most detrimental are gonorrhea and syphilis, which have increased at such an alarming rate that eugenists consider them factors of the greatest

danger to the progress of civilization. These venereal diseases are usually associated with prostitution, and it is a severe indictment of modern society that an institution responsible for so much misery and harm is tolerated and allowed to exist. Gonorrhea and syphilis, like other diseases, are not actually inherited, but they produce taints either on the germ cells or the tissues of the unborn offspring which may act in just as potent a manner as any hereditary defects. All in all, these diseases bring about such fundamental changes within the bodies of the unborn child that invariably they lead to the birth of many kinds of defective offspring. The germ cells of an individual suffering from syphilis actually become infected with the syphilitic-producing organism, so that when they take part in fertilization they bring the horrible parasite in with them. Clearly, these diseases are interfering vitally with the best evolution of man. Moreover, they afford one of the severest indictments of our modern educational system, with its utter lack of facilities for teaching men and women the meaning of sex, the *rôle* it plays in their lives, and the consequences of the abuse of the sexual powers, not only on themselves, but more particularly on future generations.

In regard to gonorrhea, competent authorities have estimated that in the city of New York eight of every ten men have at some time contracted it. Conditions in other cities, and even in rural sections, are probably much the same. At least fifty per cent of all childless marriages are due to this infection, as are from ten to twenty-five per cent of all cases of adult blindness;

moreover, about seventy-five per cent of all the cases of blindness in new-born children have been ascribed to this disease. The public does not generally know that about seventy per cent of the cases of severe internal disorders in women are directly the result of gonorrheal infection. It has also been shown that about eighty per cent of the deaths caused by infection and inflammation of the female reproductive organs are due to this venereal disease. Gonorrhea often may be driven inwards and be covered over for a long time, invariably giving the patient the false assurance that he is rid of it; but later in his life it may break out anew and attack vital organs, not only producing profound changes that cripple the system, but in many instances leading to death.

From the standpoint of its effect upon the human family, syphilis is an even more horrible affliction. It is caused by a single-celled animal, a protozoan, which invades the germ cells as well as the other vital tissues of the body, particularly those of the nervous system, causing various kinds of physical and mental degeneration. In cases where the disease is recognized and treated in its early stages, it may be permanently cured; but if it has progressed for some time, a lasting cure becomes impossible. As already mentioned, the organism producing the ailment has the tendency to attack nervous tissue, bringing about such modifications within it as to render the individual helpless. Many forms of insanity are the direct result of the degenerative changes produced in the nervous system by syphilis. Paresis, or softening of the brain, in almost

one hundred per cent of the cases is caused by this infection. The results of this disease on offspring are fairly well known. Fortunately, most of the embryos are so injured by the syphilitic taint that they do not progress very far, but those that complete their development usually show vital physical or mental defects. In such cases it soon becomes apparent that the sins of the fathers have been visited upon their children, and the tragedy of it all is that these offspring may not be the only sufferers; for each of them, through the agency of mating, may become the means of transmitting the same horrible taint to other innocent persons, as well as to unborn generations.

In regard to the transmission of the above diseases, competent authorities have shown that prostitutes are the chief source of infection in almost ninety per cent of the cases. Examination has revealed the fact that practically all prostitutes have had gonorrhea and that about eighty-five per cent of them also have had syphilis at one time or another. Certainly, all sensible people must condemn an institution which disseminates virulent venereal diseases that not only wreck many lives but also poison future generations.

There is need for eugenics in arriving at a solution of such social problems as feeble-mindedness, insanity, crime, delinquency, and pauperism, as well as such national problems as immigration and war. Heretofore, social workers, in dealing with these questions, have advocated remedies which were largely of an environmental character, either by erecting more institutions for housing the unfortunates who fall under this

classification, or by establishing more charitable organizations to help them directly. Such treatment has not been successful in reducing the number of undesirable elements in the population; on the contrary, it has tended to increase them. Many modern social workers believe with the eugenists that not a few of these defectives are born, rather than made by the environment. They are firmly convinced that the way to a better civilization is by the twofold process of encouraging individuals with desirable traits to leave more offspring, and preventing those with undesirable traits from leaving any offspring at all.

Feeble-minded and insane individuals often are classified together as neurasthenics. Although the public does not distinguish clearly between these two groups, the scientist draws a definite line of demarcation between them. A feeble-minded person is one whose mental development is deficient; such a person never grows beyond a certain stage in brain development. Insanity has to do with a disease or a degeneration of the nervous system; many people are mentally sound up to a certain age, and then become insane. These two types of mental disorder may show themselves in so many gradations that it is most important to differentiate clearly between them.

Some feeble-minded persons appear quite normal until studied; others are mentally so deficient that they can be easily identified. Psychiatrists classify the feeble-minded into three groups: namely, idiots, imbeciles and morons. The idiots, as adults, have the mentality of a normal child of two, and are incapable

of taking care of themselves. Imbeciles may have the mentality of a child of six or seven; and while they may be able to exercise their purely physical functions, they never can become self-supporting, and invariably are objects of pity and charity. The morons constitute a distinctive group in which, although physical maturity has been reached, the mental capacities have not developed beyond those of a normal child of between twelve and fourteen. Persons in this class can perform certain kinds of manual labor and may even become self-supporting, but beyond this they are incapable of achievement. Here belong many of the low-grade families, low physically, spiritually, mentally, and morally. From the group as a whole come so many of the mentally deficient types of children and adults that it constitutes a grave danger to the general population, for it has been found that feeble-mindedness is mainly hereditary. One of the real tragedies of the present day is the toleration of a marriage between a normal person and one of a low grade of mentality, for some of the children may thereby become tainted with the trait of feeble-mindedness. It must be remembered that genetics applies to human beings as well as to the lower organisms, and that feeble-mindedness is just as much an hereditary trait as color. There are genes which determine the individual type of mentality as specifically as there are genes for the type of physical make-up.

The institutional population of the feeble-minded and insane in the United States has been estimated at somewhere between eight hundred thousand and a

million — more than the total number of students enrolled in our colleges and universities. This number, moreover, does not include those who are in private asylums or homes, or at large in different communities. The cost of maintaining these defectives has steadily increased to staggering amounts, conservative calculations indicating that we spend between $500,000,000 and $1,000,000,000 annually for their support.

The criminal and delinquent classes have also been on the steady increase in the United States. The annual cost, both direct and indirect, of crime in our country is not definitely known, but estimates by competent authorities range from $10,000,000,000 to $20,000,000,000. Conditions have steadily become worse, so that at present our nation is regarded as the home of the largest number of criminals in the world. Students who have studied the criminal and delinquent classes have shown that most of them are subnormal or abnormal in one respect or another. Many of these tendencies express themselves nervously, as feeble-mindedness and insanity, the result of hereditary influences.

Concerning the question of crime in general, the American Eugenics Society makes the following significant remarks:

> Since crime is largely the result of defective intelligence, defective emotions, or a combination of both, and since a large proportion of these defects are inherited, it is obvious that anything which can reduce crime, anything which can prevent the destruction of property or prevent the thousands

of rape cases or save some of the 11,000 lives of persons who are murdered each year in the United States, deserves the consideration of the busiest individual. Eugenics is by all odds the most hopeful solution. People have been trying to reduce crime by wholly environmental means, but now, since crime and criminals are increasing with such rapidity, we must admit that such treatment is ineffective and turn to the basic solution. The discovery and committal of mentally and emotionally defective children (potential criminals) to segratories is a hopeful probability for reducing crime.[1]

It is not very difficult to find the reason why we have become the worst nation of criminals on the earth. Until very recently we have allowed foreigners to enter our country virtually without restriction, and large numbers of them have taken advantage of the opportunity. While the growth of our population is due largely to immigration, and while we have received many worth-while individuals who have developed into worthy citizens, we have also taken in many undesirables and delinquents who have, in large measure, been the stocks from which the gunman, the charlatan, and the vice vendor have sprung. Serious students of the question realize that there can be no unrestrained immigration if our country is to preserve itself. Our present immigration policy, whereby foreigners are admitted in accordance with a certain quota restriction, has improved matters somewhat, but it is far from being the most desirable solution of the problem from a eugenic standpoint.

[1] The American Eugenics Society, New Haven, Connecticut. 16-page circular, 1927–1928. p. 15.

A policy of restricted immigration based on substantial knowledge regarding the character of the incoming aliens would yield more beneficial results. Until the present time the tendency has been to judge immigrants largely on the basis of their personal appearance; if a person makes a good appearance and responds properly to simple tests, invariably he is allowed to enter. The tests applied, while they are important, nevertheless reveal nothing concerning the biological potentialities of those who seek admittance. An exhaustive investigation should be made not only of the immediate individuals, but of the families from which they derive. Needless to state, such a system of investigation would be more expensive, but it would be vastly more efficient. The investigations would have to be made in the various countries from which the prospective immigrants wish to emigrate, but this would not be as difficult a task as it at first appears. Our government maintains legations in practically all foreign countries, and it would be a rather simple matter to attach an additional group of competent investigators to them. Such inquiry would soon show what persons would or would not make desirable citizens, and would exclude many feeble-minded, insane, criminal, delinquent, and other defective persons such as we have been receiving for the last fifty years. The saving from the reduced cost of caring for these people would more than pay for the cost of maintaining the respective bureaus of investigation.

The American Eugenics Society says in regard to immigration:

Already those in key positions are noting the beneficial effects of the new immigration. Shutting off immigration altogether was not wise, and eugenicists furnished Congress with the information which changed the Nation's attitude toward the question. Whereas heretofore it has been regarded as a short time investment in productive labor, now it is regarded as a long time investment in family stocks. A further extension of eugenic policy will be to make a selection of the many applicants for entrance to America, testing them mentally, physically, and by as thorough as possible a search of their heredity to assure our Republic that the applicant carries no recessive defects likely to appear in his children. Selective immigration is practical both for ourselves and for our descendants. At present in proportion to their respective numbers there are 175 foreign-born persons in our institutions for every 100 native born citizens. The decrease of such a ratio by restrictive and selective immigration is surely practical.

Furthermore, keeping America American is exceedingly practical. Eugenics wants to prevent the unassimilable races from coming to America and mixing with our best people. Eugenics seeks to prevent dysgenic race mixture; to deport aliens who have proved themselves antagonistic to our ideals and institutions; and to register all aliens just as all citizens are required to register.[2]

The foregoing discussion has indicated many of the factors which are directing the present trend of society. Last, but not least, comes the factor of war. War, as it has been carried on in recent centuries, has been one of the worst factors in lowering the level of civilization. As everybody knows, war drains the human family of

[2] *Idem*, p. 14.

its finest manhood, and thus devitalizes individual nations in particular and civilization in general. In the process of selecting our fighting units, individuals are examined very carefully, and only those who are fittest from a physical and mental standpoint are chosen for service. The aged, maimed, or crippled are rejected. Thus, the ablest men are sent to the trenches to be killed off. As far as the actual struggle is concerned, one cannot call it a survival of the fittest, as this phrase is understood in a state of nature, for it is not always the strongest, physically and mentally, who are left, but rather those who are best equipped with guns, ammunition, poison gas, dreadnaughts, and the like. What chance has the most gifted individual before an engine of destruction which he cannot even see? One machine-gun in the hands of a moron may destroy a host of the finest manhood of a nation.

Many people argue that war is necessary as a check on the growth of the human family, which is increasing so rapidly that the world must soon be over-populated. Against this argument lies the fact that, in spite of the various wars, the human family has steadily increased in the last few centuries, particularly in the last one. Students have pointed out also that the classes which are gaining are those which are contributing the least to the advancement of civilization, whereas the others either remain stationary or actually decline. At any rate, eugenists believe that war is not a necessary solution of the problem. There are many other definite ways, sociological and biological, of dealing with the population problem.

As far as the toll in human life is concerned, it has been estimated that in the last war alone ten million people were killed, including the flower of the youth in the various combatant countries. The members of this group were permanently removed as contributors to civilization, and many of them did not even leave offspring. Undoubtedly it will take the world many centuries to recover from the slaughter and brutality of the last war, and such, of course, has been the tragic history of every war.

To anyone who critically examines the various factors which are moulding our present social order, it is evident that thus far the human family has applied remedies which have been almost exclusively environmental in character, and these have not been successful in decreasing or eradicating the defective population. Since 1900, however, largely through the enunciation of the Mendelian principles, many evidences have been accumulated to show quite clearly that the nature of an organism depends mainly on the fundamental stock from which it is derived, rather than on the environment which surrounds it. A good environment cannot possibly unmake bad heredity; the desirable traits must be there to start with. It must not be inferred, however, that good surroundings are unessential. It is quite important that the place in which an animal or plant lives be as favorable as possible in order that the best results may be obtained, but the environment alone is ineffectual without good heredity. Likewise, good heredity and a poor environment cannot be expected to yield the best products. Given a good foundation

of heredity *and* environment, then a magnificent superstructure becomes possible. These facts are so well known to all modern farmers and breeders that they may be said to underlie all recent developments in agriculture.

One of the best studies along this line is contained in the history of the "Kallikak Family," worked out by Professor Goddard when he was in charge of the school for the feeble-minded at Vineland, New Jersey. It traces for five generations two lines of offspring from a man by the name of Martin Kallikak, who came of a good Revolutionary family. On one side Professor Goddard summarizes the results of an illegitimate mating of Martin with a feeble-minded girl, and on the other side he traces the progeny of the legitimate mating between Martin and a girl of good stock. From the former union there were 480 individuals, of whom 143 were feeble-minded, forty-six normal, and the rest either unknown or doubtful. There were thirty-six illegitimate children, thirty-three sexually immoral individuals (mostly prostitutes), twenty-four confirmed alcoholics, three epileptics, eighty-two who died in infancy, three criminals, and eight brothel-keepers. Compared with this, of the 496 individuals coming from the mating of Martin and the girl of good stock, only two were alcoholics and only one sexually immoral. The legitimate children of Martin have been doctors, lawyers, judges, educators, traders and landholders; in short, men and women in good standing in every phase of social life. There were no epileptics or criminals, and only fifteen children died in infancy.

Another study of great interest from the standpoint of human heredity is one made by Dugdale, in 1875, on the Jukes family; up to that time it had cost the State of New York over $1,250,000 to care for the defective progeny to which it had given origin. Dugdale's investigations, based on a study of nearly twelve hundred individuals, showed that this family had produced three hundred and ten professional paupers, four hundred and forty physical wrecks from debauchery, fifty prostitutes, and more than two hundred criminals, seven of whom were convicted for murder. It also is definitely known that among the Jukes there were three hundred deaths in infancy.

The name of this family was, of course, fictitious, but in 1911 Dugdale's original records were found and these gave the actual names and addresses of various representatives whom he had investigated. Dr. Estabrook, of the Eugenics Record Office, Carnegie Institution, was thus enabled to trace the further history of this stock, and in 1916 he published his results under the title of *The Jukes in 1915*.[3] Dr. Estabrook's investigation included a large number of representatives, a total of 2,094, and in all essential details they agreed with the findings of Dugdale; namely, that this was and still is a shiftless, worthless, and intemperate family, incapable of contributing anything to society except its defective progeny.

In the case of the Jukes, as in that of the Kallikaks, it becomes evident that the environment does not seem to play much of a part in bringing about improvement,

[3] The Carnegie Institution of Washington, 1916.

since many of these deficient individuals were raised and cared for under good environments. It seems definite that heredity is the most potent factor in determining the type and character of the individual.

Another interesting study has been worked out by Poellman, of Bonn, in tracing the history of the Zero family of Denmark, a defective group of beggars and criminals. Poellman has shown that this family started with a female who was a confirmed drunkard. and in six generations she gave origin to progeny totaling over eight hundred, among whom were 181 prostitutes, 107 illegitimate children, 102 professional beggars, 54 inmates of almhouses, 76 individuals convicted of serious crimes, and 7 murderers.

Numerous other studies of a similar nature have been made, such as the Hill Folk, the Hickory Clan, the Nam family, and the Tribe of Ishmael, all revealing the same sad histories. Other investigations also have been conducted to show that good traits likewise are transmitted from generation to generation, accounting for wholesome and desirable citizens, thereby insuring a finer and nobler civilization. One of the best studies of this kind is that which has been made of the Jonathan Edwards family, starting in Puritan times with Jonathan Edwards, who was responsible for 1394 descendants in 1900, all of whom were good substantial citizens, many of them attaining prominence as teachers, lawyers, physicians, clergymen, business men, statesmen, etc. As far as could be determined, not a single member of this family was ever convicted of a crime.

It has also been established that special gifts may be perpetuated in certain families, through the careful mating of individuals, coupled with the maintenance of an environment in which such gifts find their fullest expression. The Darwin family in England has produced many distinguished scientists for several generations. In reviewing the history of evolution, it was seen that Erasmus Darwin, the grandfather of Charles Darwin, was one of the great physicians and evolutionists of the eighteenth century. Charles Darwin himself is regarded as the greatest evolutionist of all times. The sons of Charles Darwin have played important *rôles* in furthering scientific developments in the present century. Major Leonard Darwin, now living in England, is one of the world's greatest students of eugenics, and a past president of the International Eugenics Society. A cousin of Charles Darwin, Sir Francis Galton, distinguished himself in many fields of biology, and was the founder of the modern movement of eugenics. In music, the Bach family can be mentioned as having contributed many musicians of eminence, the greatest of whom was Johann Sebastian Bach, whose compositions for the organ have never been equalled or surpassed.

Heredity, mainly, was responsible for the production of these gifted individuals, rather than environment. Dr. Frederick Adams Woods, in a very interesting book entitled *Heredity in Royalty*,[4] indicates how potent heredity is in making us what we are. He chose royalty as the basis for his study because, in most

[4] New York, Holt, 1906.

instances, the records for royal families are more complete than for others, and also because the royal lines have guarded their blood rather zealously, absolutely forbidding members from marrying beneath their particular station. Therefore, royalty must be regarded as the most inbred human group for which records are available. Dr. Woods shows that, in spite of environment, such physical and mental traits as feeble-mindedness, insanity, talents of one kind or another, types of chin, types of nose, etc., have been handed on as definitely as any pedigreed traits among the lower animals.

In recent years, scientists have seriously considered the question of the potency of heredity and environment. Aside from the studies which have been mentioned, the factors have been carefully investigated and tested on identical twins (Figure 75). Identical twins are a pair of individuals who have the same heredity, inasmuch as they have been produced through the complete separation of the first two embryonic cells of the fertilized egg immediately after it began its development. Since a single pair of opposite germ cells was responsible for the twins, they possess the same hereditary make-up, and therefore they appear alike in all respects; physique, stature, sex, mental capabilities, etc. Even the mother finds it difficult to distinguish between them as children, and this likeness continues later in life. Galton and others have studied a large number of identical twins, some who were reared in the same environment, and others who were reared apart, subjected to different surroundings. In the

FIG. 75. IDENTICAL TWINS

former case it was found that the twins were so absolutely alike that they could not be distinguished. In the latter case the separate environment seemed to make little difference, and when the histories of the individuals were carefully checked over, it was discovered that in spite of the isolation and exposure to different environmental influences, nevertheless, basically, the individuals' physical and mental behavior was similar. If environment, rather than heredity, is the all-important influence, as so many conscientious citizens advocate, why should not these individuals, exposed to radically different conditions of the environment, become markedly different instead of remaining similar in virtually all respects?

Assuredly such investigations as those mentioned above indicate quite conclusively that, in the main, good heredity accounts for good offspring, and poor heredity for poor offspring. The eugenist is convinced that the present-day treatment of the defective population is not bringing about the results hoped for, because it is helping rather than hindering the increase of undesirable citizens.

In the circular of the American Eugenics Society already referred to, the following assertions are made regarding the rapidly mounting costs for maintaining our socially undesirable classes:

> Business men should be among those most interested in the subject. Eugenics touches industry as well as the individual and the nation. Business men are constantly complaining of the difficulty of obtaining high grade executives. It has been carefully estimated that today there are needed

over six million very high grade men in industry, while the supply is less than a quarter of that amount. The deficit accounts readily for the inefficiency of many sorts, so widespread and so much lamented. Bad germ-plasm eventually tends to destroy economic efficiency. Training needs material to work on to be effective, and training alone is not sufficient to develop capacity and reasoning power. High grade men must first be born and then trained. Eugenics knowledge by high grade parents will help to increase the number because few parents want to see their family become extinct, and a knowledge that four children are required to avoid this fate is already making itself felt. People hadn't thought much about family death until eugenists called their attention to it.

Raising high type children makes education a good investment. We need more educable people and the only way to get them is to raise them.

Philanthropists are becoming more and more interested. The greater part of charity goes to the unfortunate victims of bad heredity. Instead of lessening the need for charity, much of our philanthropy makes it more imperative. Eugenics is a charity to lessen charity.

From a dollars and cents standpoint the following will interest anyone.

Various estimates have placed the cost of crime to the United States at from ten to twenty billion dollars a year. Crime costs the average family $500 a year directly and indirectly. The direct loss from crime is believed to be about $33 per year per person. New York spends $8 per person per year on law enforcement alone. A single criminal conviction costs $2,200.

Over 650,000 persons were committed to jail in the United States in 1925. The United States has one murder for every 10,000 of its population. England, on the other hand, has

one murder for every 236,000 of its population. In some cities the chances of encountering the assassin's bullet is one in 1,000 for adults.

A little discussed phase of the crime problem is prostitution. It is estimated that 90% of all venereal disease is spread by prostitutes. Syphilis alone kills more people than any other disease, 222 per hundred thousand against 140 for tuberculosis, its nearest rival.

It must be remembered that the majority of criminals have either defective intelligence, defective emotions, or a combination of both defects. Only recently has psychiatry advanced sufficiently to understand the basic problem of crime. This is acknowledged by all authorities and it is now possible to attack the problem at its source instead of trying to do repair jobs as our forefathers have done. It is estimated that if only a small proportion of the amount of money lost through crime in the United States each year were to be spent on testing children in schools and segregating them that the money and health loss through crime would be reduced more than 50% in two generations. It is true that venereal disease sterilizes the prostitutes in the majority of instances and thus eliminates their descendants from the race, but the terrific death and disease toll which they cause is tremendous and this too could be lessened speedily.

In 1915 the United States as a whole spent $75,000,000 on the care of defective and delinquent classes. This is a direct cost. For the fiscal year ending June 30, 1928, New York State has appropriated $32,558,831.46 for the care of the feeble-minded, insane, criminalistic, epileptic, blind, deaf, pauperous, and other institutionalized and socially aided classes. This amounts to 15.9% of the total expenditures of the state. In 1915 New York appropriated $11,230,856.35. It must be remembered that this again is the

direct cost to one state, and it is mounting each year. The indirect cost is far in excess of this, many times greater, in fact, and it is believed on good authority that the greater part of this money is simply paying for bad heredity.

Each year the cost mounts up. Taking New York State as an example, we may consider that the $32,558,000 represents not the cost to New York, but the interest, say 6% on an amount which would have to be invested to produce this much money at 6%. That would be $542,646,000 that we can consider the State of New York has invested in its feeble-minded, insane, criminalistic, epileptic, blind, deaf, pauperous and other institutionalized and socially-aided classes. Is it not worth-while to try and reduce this stupendous investment which is becoming an increasing burden year by year to the citizens of the state?

From the Army Mental Tests it has been concluded that we now have in the United States roughly 25,000,000 persons lacking sufficient intelligence to get into high school to say nothing of passing through the four years there. We have 80,000 paupers as inmates of almshouses in the United States. It has been estimated that there are four cases of legal insanity (a person must be pretty bad to be considered legally insane) per thousand inhabitants in New York State. During one generation one person out of 25 becomes a resident of a state hospital for mental defectives. One family in every seven is represented, and it has been conservatively estimated that there are five to six times as many mentally diseased people outside asylums as in them. There are 2,340,000 such persons in the United States as a whole. It would not be possible to figure in dollars and cents the misery which these people cause to themselves and to the persons upon whom they are dependent outside of the state. The amount would be stupendous, and a very large part of this human misery could be quickly, painlessly, and

mercifully eliminated in a few generations by proper application of eugenics.[5]

Students of these questions have pointed out repeatedly that civilization is now confronted with a twofold dilemma: the decrease of the gifted, desirable population, and the rapid increase of the defective, undesirable population. Statisticians have been gathering figures along these lines for a number of years and, although they are deficient in many respects, they are convincing enough to indicate the seriousness of the situation. Bearing these facts in mind, evolutionists and eugenists have formulated a number of remedies, which, if followed for a few generations, would lead gradually to social betterment.

Society should educate parents and children along lines of clean living and a correct understanding of the problems of heredity and sex. Every child should be taught the beauty, the nobility of his or her sexual powers. Parents must come to the full realization that nothing good can result from a belief in the commonly accepted view that ignorance of sexual matters means virtue and innocence. Such a policy has led to secretiveness on the part of children, with the result that sexual vices and all their accompanying social evils have multiplied. Ignorance can lead only to misconception and error, making possible the prevalence and continuance of prostitution, venereal diseases, sterility, and the decline of man.

People must be educated to regard marriage with greater seriousness, and everybody should be made to

[5] *Op. cit.*, pp. 15–16.

understand the social significance of marriage as an institution. At the present time so many persons regard the ancient custom of marriage with such utter indifference that there has been an alarming increase of hasty unions and consequent divorces. Needless to say, such a state of affairs vitally interferes with the efficiency of the family, particularly where children are involved. The family, after all, is the basis of our social order, and anything which tends to undermine its strength inevitably leaves its mark on the entire fabric of civilization. Companionate marriage, trial marriage, common law marriage, and a host of other similar types of marriage are leaving their impress on our immature youth, leading them to think lightly of this most important step in life, which should be undertaken only after the most careful judgment and realization.

Society should deal humanely with those individuals who are socially irresponsible, but it must prevent them from reproducing their kind. As has been pointed out already, many of these unfortunates are produced from human beings who possess undesirable traits, so that the only sure method of reducing their number is to prevent such persons from bringing children into the world. Each community should demand physical and mental examinations of all persons who propose to marry. Society should be interested not only in the monetary possessions of the contracting parties, but also in the good or bad traits brought into the union. Every person should be made to feel genuinely proud of possessing a splendid heritage. It would then be a relatively simple matter for every state to insist

that a health certificate accompany every marriage license.

Evolutionists and eugenists have no desire to produce a new race of people, but they insist, so long as the facts show that defective as well as desirable traits are transmitted through heredity and maintained by environment, that the only way to insure continued improvement is to prevent undesirable types from reproducing their kind, and at the same time to encourage desirable types to perpetuate their kind in larger measure.

Man really has it in his own power to plan his future. In past generations he has mapped out the path of evolution for many of the lower forms. Like them, he is bound and fettered by natural laws, and with his greater degree of intelligence he may also chart his own evolutionary course, producing improvements which will express themselves in a finer and nobler civilization.

GLOSSARY

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ACCESSORY CHROMOSOME — A special chromosome (X or Y), known also as the odd chromosome, that appears to carry determiners for sex.

ACQUIRED CHARACTER — A modification produced in a bodily structure as the result of some environmental or functional stimulus.

ALCHEMY — The crude chemistry of the middle ages, the chief aim of which was to effect the transmutation of base metals into gold.

ALPHA PARTICLE — One of the positively charged particles which comprise the alpha rays that emanate from a radio-active substance. These particles really are helium atoms minus two electrons, and are called "protons."

AMINO-ACID — One of several organic acids, modified by the replacement of one hydrogen atom by the radical NH_2. These acids are the foundation of the proteins.

AMPHIBIA — The class of vertebrates, including representatives such as toads and frogs, which are capable of life either in water or on land.

AMPHIMIXIS — The intermingling of maternal and paternal germ-plasms during reproduction.

ANABOLISM — Constructive metabolism. See METABOLISM.

ANATOMY — The science of the structure of organisms.

ANNELIDA — The phylum containing the segmented worms such as the earthworm and leech.

ANTHROPOIDEA — A sub-order of the primates, composed of the most highly developed forms, including man.

ARBOREAL — Tree-dwelling in habit.

ARCHEOLOGY — The science concerned with the systematic investigation of historic and prehistoric relics of man.

ARCHEOZOIC — The first era of the geologic time scale.

Arthropoda — The phylum characterized by jointed appendages; includes such forms as insects, crustaceans and spiders.

Astronomy — The science that deals with the celestial bodies.

Atom — The smallest division of an element which can exist either alone, or in combination with other elements to form a molecule.

Atomic Evolution — The evolution of the chemical elements.

Atrium — The chamber in Amphioxus, into which the gill slits open.

Autosome — One of the ordinary chromosomes. All chromosomes, except the accessory ones, are termed autosomes.

Aves — The class of vertebrates which includes the birds.

Beta Particle — One of the negatively charged particles which comprise the beta rays that emanate from a radio-active substance. These particles are the "electrons."

Biogenetic Law — In the development of the individual, the history of the race or group is repeated.

Biological Immortality — Immortality carried on, generation after generation, by means of reproduction.

Biology — The science that deals with living matter, including plants and animals.

Biometry — The application of the statistical method to biological problems.

Carnivorous — Flesh or meat eating.

Cataclysm — A violent and extensive transformation of the natural phenomena.

Catalyzer — An agent causing change in a chemical compound, and remaining itself unchanged.

Catarrhini — A division of Anthropoidea which includes the old world apes, monkeys, and man.

Caudal Vertebræ — The vertebræ or bones of the tail.

Cell — The fundamental unit of organization of living things.

Cenozoic — The fifth era of the geologic time scale during which the birds and mammals became definitely established.

CENTROSOME — A minute single or double body of protoplasm found near the nucleus in the cytoplasm of a cell. It plays an important part in indirect cell division — mitosis — and is considered the center of activity during that process.

CHEMISTRY — The science of the particulate constitution of matter.

CHLOROPHYLL — The green coloring matter in plants, the function of which appears to be to extract energy from the sun's rays and convert it into chemical energy for the plant's use.

CHOANOCYTE — One of the flagellated collar cells found in sponges and protozoans belonging to the Choanoflagellata.

CHOANOFLAGELLATA — A group of Protozoa composed mainly of choanocyte cells.

CHORDATA — The phylum of animals characterized by the possession of rod-like structure — the notochord.

CHROMATIN — The deeply staining matter found in the nucleus of the cell, out of which the chromosomes are organized during mitosis.

CHROMOSOME — One of the bodies into which the chromatin becomes organized during mitosis, the number being constant for species. The chromosomes carry the hereditary determiners.

CLEAVAGE — The mitotic division or segmentation of the fertilized ovum.

COCCYX — The caudal or tail end of the spine.

COELENTERATA — The phylum of animals which have a gastrula form, including jellyfishes, set anemones, and comb-jellies.

CŒLOM — The true body cavity, situated between the body wall and the digestive tract.

COLLOID — A glue-like substance, uncrystalline, with practically no powers of diffusion through membranes.

COMPARATIVE ANATOMY — The science of structure, studied from the standpoint of the comparison of related parts.

COMPOUND — The combination of two or more elements.

CONTINUOUS VARIATION — Small variations which continue to

appear over a long period of time. See FLUCTUATING VARIATION.

COSMIC EVOLUTION — The evolution of the universe.

COSMIC PANSPERMIA — The theory of the origin of life on the earth which states that it was brought here in the form of minute living particles from some other heavenly body.

CRÔ-MAGNON — A race of primitive men, fossils of whom were found at Crô-Magnon, France; they are believed to have lived at the same time as the Grimaldi race.

CROSSING OVER — The interchange of genes of homologous chromosomes thought to take place during the process of synapsis.

CRYSTALLOID — A crystalline substance which forms a true solution and diffuses readily through membranes.

CTENOPHORA — The class of coelenterates designated as comb-jellies.

CYCLOSTOMATA — The most primitive class of Chordata including such forms as lampreys and hagfishes.

CYTOLOGY — The microscopic study of cells, especially germ cells.

CYTOPLASM — All living material of a cell between the outer cell wall and nucleus.

DARWINIAN — A believer in the conception of evolution as propounded by Darwin.

DEDUCTIVE METHOD — A method of scientific research in which a general law is preconceived and all facts made to agree with it.

DETERMINER — See GENE.

DIHYBRID CROSS — A cross considering two traits in which the parents differ.

DIMORPHISM — The quality of existing as two distinct types.

DIPLOBLASTIC — Possessing two distinct layers of tissue, ectoderm and endoderm.

DIPLOID — Referring to the full or duplex number of chromosomes found in body cells and immature germ cells.

Discontinuous Variation — Sudden variation which may be very large or small. See Mutation.

Dominant — Term used to denote the characteristic which expresses itself in the offspring, covering over a similar, but weaker, characteristic received from the opposite parent.

Drosophila — A genus of flies, used in breeding experiments.

Duplex — See Diploid.

Echinodermata — The phylum of animals that is characterized by having a spiny skin and is made up of such forms as starfishes, sea urchins, and sea cucumbers.

Ecology — The science that deals with the relation of organisms to their environment.

Ectoderm — The outer layer of cells of the gastrula.

Elasmobranchii — The class of fish-like vertebrates that possesses a cartilaginous skeleton and includes sharks and rays.

Electron — The smallest known component of matter, which always bears a unit charge of negative electricity.

Element — One of the fundamental units of chemistry out of which the compounds are constructed. In an element the atoms are all alike.

Emboîtement Theory — Bonnet's belief that the germ cells contain miniature models of all individuals to be born. Also called encasement theory.

Embryology — The branch of biology that deals with the development of the individual before birth, that is, before it reaches adult appearance.

Encasement Theory — See Emboîtement Theory.

Endoderm — The inner layer of cells of the gastrula.

Entelechy — The name given by Aristotle to the perfecting principle that he thought actuated living matter.

Eoanthropus Dawsoni — The so-called Piltdown man, discovered in Sussex, England, and estimated to have belonged to a primitive race which existed about four or five hundred thousand years ago.

Eohippus — An early ancestor of the modern horse, which existed during the Eocene period.

EPIGENESIS — Wolff's theory that the male and female gametes each contribute simple stuffs to the embryo, which, through growth and development, become more highly organized.

EQUATIONAL DIVISION — The ordinary division during which each chromosome divides equally.

EQUINE — Pertaining to the horse.

EQUUS — The modern horse.

ETHNOLOGY — The science which is concerned with the study of man from the analytical, comparative and historical standpoints.

EUGENICS — The science of improving the human race by the application of the laws of heredity and environment.

FACTOR — See GENE.

FAUNA — All of the animals inhabiting a given area.

FERTILIZATION — The union of the male and female germ cells.

FLORA — All of the plants found in a given area.

FLUCTUATING VARIATION — Small plus or minus variations due to environmental differences, which are not inherited. See CONTINUOUS VARIATION.

FOSSIL — A relic of an organism which existed in bygone ages, buried in the earth's crust.

GAMETE — A reproductive or germ cell.

GAMMA RAY — The short wave-length pulsation from a radio-active substance that is identical with the X-ray.

GASTRULA — A two-layered larva in the development of the many-celled animals.

GEMMULE — See PANGEN.

GENE — Same as factor, determiner, or unit. The genes are entities, chemical or otherwise, within the chromosomes responsible for the expression of inherited traits.

GENETICS — The science of the resemblances (heredity) and differences (variation) exhibited by organisms related by descent.

GEOLOGIC EVOLUTION — The development of the various formations that constitute the earth.

GEOLOGY — The science of the earth formations.

GERM-PLASM — The material of the reproductive or germ cells which forms the material basis of inheritance.

GERM-PLASM THEORY — Theory propounded by Weismann that only those traits are expressed in offspring which were a part of the parental germ cells.

GONORRHEA — A venereal disease caused by a bacterial organism.

GRAVITY — The force of attraction that the particles of matter in space exert upon one another.

GRIMALDI RACE — A race of fairly modern men, fossils of whom were discovered at Mentone, France. It is believed that they existed at the same time as the Crô-Magnons.

HEMOGLOBIN — The pigment that gives color to red blood.

HERBIVOROUS — Plant-eating in habit.

HEREDITY — The resemblance exhibited by individuals related by descent.

HOMINIDÆ — The family to which the various races of ancient and modern man belong.

HOMO HEIDELBERGENSIS — The Heidelberg man, remains of whom were found near the city of Heidelberg.

HOMOLOGY — The study of the deep-seated resemblances of corresponding parts, due to a similarity of origin, such as the wing of a bird, flipper of a whale, and the arm of man.

HOMO NEANDERTHALENSIS — The Neanderthal man, skeletons of whom were found in the Neanderthal Gorge of the Diesel River in Germany.

HOMO RHODESIENSIS — The Rhodesian man, comparatively close to modern man, whose remains were found in Northern Rhodesia, Africa.

HOMO SAPIENS — Modern man.

HYBRID — The progeny of parents differing in one or more characters.

HYDROSPHERE — The portion of the earth that consists of water.

IDIOT — A feeble-minded individual, possessing the mentality of a normal child of two.

Ids — Term used by Weismann to denote the substances of which he thought the chromosomes were composed.

Imbecile — A feeble-minded person who, though capable of exercising purely physical functions, does not develop beyond the mentality of a normal child of six or seven.

Inductive Method — The scientific method introduced by Francis Bacon which requires that a conclusion be drawn only after the facts have been ascertained through exact observation and experiment.

Inorganic — Term used to denote non-living substances. In chemistry, "inorganic" refers to anything lacking the element carbon.

Intussusception — Growth in living things, accomplished by putting new parts between the old.

Invertebrate — Any animal without a backbone.

Irritability — The power of response to stimuli.

Katabolism — Destructive metabolism. See Metabolism.

Lamarckian — A believer in Lamarck's view of evolution through the principle of the use and disuse of organs and inheritance of acquired modifications.

Lemuroidea — A sub-order of the primates embracing the more primitive forms.

Linkage — Inheritance of groups of traits, due to the fact that their genes are located in the same chromosome.

Lithosphere — The land formations of the earth.

Lophophore — The horseshoe-shaped organ surrounding the mouth of representatives of the phylum Molluscoida.

Luminiferous Ether — The hypothetical substance that fills all space.

Mammalia — The class of warm-blooded vertebrates, characterized by having hair, mammary glands, and internal development of young.

Matter — That of which the universe is composed, possessing mass and dimensions.

MEAN — The average between two extremes or several quantities.

MECHANISM — That belief which regards all manifestations as machine-like expressions of particles and forces.

MENDELISM — The experimental study of heredity based on the principles developed by Gregor Mendel.

MERYCHIPPUS — The first grazing horse, developed during the Miocene period.

MESODERM — The middle layer of tissue of the embryo of three-layered or triploblastic organisms.

MESOHIPPUS — The horse common during the Oligocene period.

MESOZOIC — The fourth era of the geologic time scale.

METABOLISM — The sum total of the changes occurring in living matter involving both the breaking down — katabolism — and the building up — anabolism — of protoplasm.

METAMERE — One of the series of homologous divisions in a segmented or metameric organism.

METAMORPHOSIS — That type of development represented by the butterfly or frog, in which the organism passes through a number of freely existing intermediate stages before it reaches the adult condition.

METAPLEURAL FOLDS — A pair of thick folds along the lateral margins of Amphioxus, which are believed to be the forerunners of the paired limbs of true vertebrates.

METAZOA — All multi-cellular animals, in which the cells have become differentiated into at least two tissue layers.

MOLECULE — The smallest combination of atoms that will form a given chemical compound.

MOLLUSCA — The phylum of invertebrate animals, which includes such forms as oysters, clams, and snails.

MOLLUSCOIDA — The phylum, including such forms as the brachiopods — lamp shells — all the members of which possess a lophophore.

MONOHYBRID — The result of a cross between two individuals differing in only one trait.

MONOTREME — The lowest order of mammals, including such forms as the duck-bills of Australia.

Moron — A feeble-minded individual who cannot develop in intellectual capacity beyond that of a normal person of twelve or fourteen years.

Morphology — The branch of biology concerned with the form and structure of organisms.

Mutation — A sudden, distinct variation, either large or small, which is inherited. Known also as discontinuous variation, saltation, and sport.

Nebula — One of the fog-like masses of gaseous matter found in the heavens. Each nebula is considered the basis for a universe similar to our own.

Nemathelminthes — The phylum of threadworms or roundworms.

Neo-Lamarckian — A believer in parallel-induction. See Parallel-Inductionist.

Nephridia — Paired tubes for the excretion of liquid waste, found in certain invertebrates. They are particularly developed in the Annelida.

Neuron — A nerve cell with all its processes and extensions.

Neutron — A close combination of a proton and an electron. Term coined by Sir Ernest Rutherford.

Nictitating Membrane — The third eyelid, also called *plica semilunaris,* which is functional in some vertebrates, and degenerate in others.

Notochord — A tough rod, resembling a stiff jelly in consistency, found to lie dorsal to the digestive system at some time during the development of all chordates.

Nucleus — The more condensed part of the cell which is the center of all activity. It contains the chromatin, the heredity-bearing material.

Odd Chromosome — See Accessory Chromosome.

Ontogeny — The development of the individual.

Oögenesis — The maturation process of the female gamete, the ovum.

ORGANIC — Term used to denote living substance. In chemistry organic refers to anything which includes the element carbon.

OROHIPPUS — The horse existing in the middle of the Eocene period.

ORTHOGENESIS — The theory that evolution proceeds by means of variation in a definite direction.

OSMOSIS — The process of the diffusion of a liquid through a membrance.

OSMOTIC PRESSURE — The pressure exerted on a membrane during the process of osmosis.

OVIST — A believer in the preformationist theory; one who believed that the ovum rather than the spermatozoön held the miniature individual.

OVUM — The female germ cell.

PALEONTOLOGY — The science that treats with the ancient life of the earth, that is, with fossil remains.

PALEOZOIC — The third era of the geologic time scale.

PANGEN — One of the small particles which Darwin believed to be budded off from the cells of the body to become stored within the germ cells. Same as gemmule.

PANGENESIS — The theory propounded by Darwin to account for inheritance.

PARALLEL-INDUCTION — The parallel modification of bodily structures and the germinal determiners responsible for their expression.

PARALLEL-INDUCTIONIST — A believer in the view of heredity by the parallel-induction of similar modifications of somatic structures and the germinal entities which bring about their expression.

PARESIS — A disease of the nervous system which brings about a general paralysis of the individual.

PARTHENOGENESIS — The development of eggs without the agency of fertilization.

PHOTOSYNTHESIS — The process carried on by the chlorophyll of plants in extracting energy from sunlight and utilizing it

in the manufacture of carbohydrates from carbon dioxide and water.

PHYLOGENY — Development or evolution of the race or group.

PHYLUM — One of the major divisions of the animal world.

PHYSICS — The group of sciences that treats of the phenomena associated with matter in general, but excluding the laws pertaining to biology and chemistry.

PHYSIOLOGY — The science of organic functions.

PISCES — The class of vertebrates made up of fishes.

PITHECANTHROPUS ERECTUS — The Java Ape-man, remains of whom were found on the island of Java.

PLANET — One of the major bodies that revolve around the sun.

PLANETESIMAL — One of the small planetary bodies which, according to the planetesimal hypothesis, aggregate in the course of time to form planets.

PLANETOID — A minor planet.

PLATYHELMINTHES — The phylum of flatworms, including parasitic and free-living forms.

PLATYRRHINI — A division of Anthropoidea including the new world monkeys.

PLICA SEMILUNARIS — See NICTITATING MEMBRANE.

PLIOHIPPUS — The first one-toed horse.

POLYPEPTID — A compound formed by the union of more than three amino-acids.

POPULATION — A mixed group of individuals.

PORIFERA — The phylum of sponges.

PREFORMATION — The view that the complete organism existed as a miniature model within the germ cell.

PRIMATES — The order of mammals to which apes and human beings belong.

PROTEROZOIC — The second era of the geologic time scale.

PROTON — A particle of an atom of matter bearing a charge of positive electricity.

PROTOPLASM — The viscid, semi-fluid substance that makes up the cells of living matter.

PROTOZOA — The first phylum of the animal kingdom, composed mainly of unicellular animals.

PSYCHIATRY — The science that deals with mental diseases.

PSYCHOZOIC — The most recent era of the geologic time scale, embracing the last million years.

PURE LINE — The progeny of parents in all of whom the germinal determiners are identical with respect to the traits in question.

RADIO-ACTIVE — The quality possessed by a substance of spontaneously undergoing disintegration and emitting alpha, beta, and gamma rays.

RECESSIVE — That entity or trait which is covered over by the dominant in a cross.

REDUCTION DIVISION — That division during the maturation process of the germ cells in which the double or somatic (duplex) number of chromosomes is reduced to the single or germinal (simplex) number.

REPTILIA — The class of vertebrates including snakes, lizards, turtles and crocodiles.

RUDIMENTARY STRUCTURE — A part of the body which has atrophied through disuse or changed conditions. Same as vestigial structure.

SALTATION — See MUTATION.

SATELLITE — One of the smaller bodies of the solar system which revolve around the planets.

SCHOLASTICISM —The dogmatic school of theology which dominated all thought during the medieval period.

SCIENCE — That organized body of knowledge based on accurate and reliable observation.

SEGMENTATION — See CLEAVAGE.

SEROLOGY — The science of the reactions of blood.

SERUM — The clear liquid of the blood.

SIMIIDÆ — The family to which such forms as the chimpanzee, gorilla, and orang-utan belong.

SIMPLEX — Referring to the single set of chromosomes found in the mature germ cells.

SOMATIC — Referring to the body.

Somatoplasm — The material of the somatic or body cells, in contradistinction to the germ-plasm.

Speciation — The making of species.

Spectroscope — An instrument for the study of the rays emitted from glowing objects such as stars.

Spectrum — The color image produced when the light emitted from a glowing object is broken into its component parts.

Spermatogenesis — The maturation process of the male gamete, the spermatozoön.

Spermatozoön — The male germ cell.

Spermist — A believer in the preformationist theory who thought that the spermatozoön rather than the ovum held the miniature individual.

Spontaneous Generation — The theory that living organisms were constantly originating spontaneously in nature out of the simple inorganic elements of the environment.

Sport — See Mutation.

Synapsis — The stage in the maturation process of the germ cells in which similar chromosomes line up in pairs for the reduction division.

Syphilis — A venereal disease caused by a protozoan parasite.

Tornaria — The larva of the primitive chordate Balanoglossus, somewhat resembling the trochophore.

Tracheæ — Air tubes in various animals.

Trihybrid Cross — A cross considering three traits in which the parents differ.

Triploblastic — Possessing three distinct layers of tissue, ectoderm, endoderm and mesoderm.

Trochelminthes — The phylum of animals to which forms such as the rotifers belong.

Trochophore — A free-swimming, ciliated larva found during the development of numerous invertebrates.

Unit-Character — A trait which behaves as a single indivisible entity in heredity.

VARIATION — The difference exhibited by organisms related by descent.

VERTEBRATE — An animal that possesses a bony skeleton.

VESTIGIAL STRUCTURE — See RUDIMENTARY STRUCTURE.

VITALISM — That belief which regards all manifestations as an expression of particles and forces plus an unknowable non-material entity.

WEISMANNIAN — A believer in the view of the germ-plasm theory of heredity as enunciated by Weismann.

ZOÖLOGY — The science of animals.

ZYGOTE — The fertilized ovum, the initial start of the new organism.

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